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NATIONAL BUREAU OF STANDARDS REPORT

9473

Comparison of Digital Computer Simulations of Thermal Environment in Occupied Underground Protective Structures With Observed Conditions

By

T. Kusuda and P. R. Achenbach
Building Research Division
National Bureau of Standards

December 1966

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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[2] Located at Boulder, Colorado, 80302.

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ERRATA

NOTE: First number indicate page, second number indicates line

VI 21

Change $\nabla^2 = \frac{2^2}{2X^2} + \frac{2^2}{2Y^2} + \frac{2^2}{2Z^2}$ to $\nabla^2 = \frac{\partial^2}{\partial X^2} + \frac{\partial^2}{\partial Y^2} + \frac{\partial^2}{\partial Z^2}$

6 4 Change N_g to h_g

69 10 Change t_s, to t'_s

69 12 Change T_v, to t'_v

71 2 Change "references 5 and 6" to "references 12 and 13"

72 18 Change "$i + 1$, t_w, $i + 1$" to "($i + 1$)th row, t_w, $i + 1$"

72 19 Change $(t_i - t_s)$ to $(t_i - t_{sc})$

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SUMMARY
OF
RESEARCH REPORT

COMPARISON OF DIGITAL COMPUTER SIMULATIONS OF THERMAL ENVIRONMENT IN OCCUPIED UNDERGROUND PROTECTIVE STRUCTURES WITH OBSERVED CONDITIONS

by

T. Kusuda
P. R. Achenbach

December 1966

Prepared for
Office of Civil Defense
Department of the Army-OSA
under
Control No. OCD-OS-62-44
Unit 1211A

This is a summary of a report which has been reviewed in the Office of Civil Defense and approved for issuance. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

**Summary prepared by
National Bureau of Standards
December 1966**

The National Bureau of Standards has been engaged in the heat transfer analysis of underground installations for the past several years. This report covers a part of the Bureau's activities related to the computer simulation of the thermal environment for prototype shelters.

The computer was used basically to simulate energy balance in the shelter living space and to analyze heat conduction from the shelter walls (including ceiling and floor) to the surrounding earth.

For the heat conduction analysis, finite difference techniques were employed; using a three dimensional model in some cases and a one dimensional model for the remainder.

Digital computer programs were developed and applied to seven different prototype shelters for which temperature and humidity records with simulated occupants were available as a result of studies by the National Bureau of Standards and by the University of Florida. In the seven shelters used for the investigation, twelve different operating conditions were analyzed. Of these twelve conditions, ten were under summer operation and two under moderate winter conditions.

Generally the agreement between the computed and observed thermal environment on these prototype shelters was surprisingly good, in spite of the fact that numerous simplifications were involved in describing the complex shelter heat transfer system for computer analysis. Two inherent uncertainties exist, which influence the final reliability of the calculations. The first involves the description of the actual complex system by mathematical language (or operat' ıl uncertainty). The second is related to the accuracy of input data used for the calculations, (or data uncertainty). Often, these are interrelated.

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In this study, the following four different computer models were studied and two of them were extensively utilized for the comparison of calculated thermal environment with the observed data in the prototype shelters.

M-(1) Three-dimensional rectangular model with composite walls and with separate initial temperature patterns normal to the six bounding surfaces.

M-(2) Three-dimensional rectangular model with homogeneous heat conduction medium having separate initial temperature patterns normal to the six boundary surfaces.

M-(3) One-dimensional compound model for six composite wall systems.

M- (4) One-dimensional compound heat conduction model, same as M-(3) except that the roof region was assumed adiabatic.

To simulate the initial earth temperature distribution, the following three modes were employed:

I-(1) Earth temperature gradients normal to the six bounding surfaces.

I-(2) Earth temperature gradient normal only to the ground surface.

I-(3) Initial earth temperature constant around the shelter.

One of the factors not well established for calculating the shelter heat transfer is the heat exchange between the shelter air and the inner surfaces, between the occupants and the surfaces, and among the surfaces.

The analysis of simultaneous exchange for radiative and convective energy among occupants, air and inner surfaces of a shelter is very complex, and it requires the solution of a set of integral equations which are difficult to solve for even very simple geometrics. Therefore conventional combined heat transfer coefficients for radiation and convection were used in the analysis. Several numerical values and combination of these combined coefficients were assigned to the six interior surfaces to study the overall effect on shelter thermal environment.

Findings

1) A soil analysis of the earth around most of the prototype shelters indicated that the thermal diffusivity and thermal conductivity were in the neighborhood of 0.02 ft^2/hr and 0.75 Btu/hr, $(ft)^2$, $^{\circ}F$/ft respectively. These values, in turn, seem to result in a good agreement between the calculated and the observed earth temperature change surrounding prototype shelters.

2) The following combined heat transfer coefficients at the shelter inner surfaces produced satisfactory simulation of the shelter summer environment for most of the prototype shelters.

1.0 Btu/hr. (ft^2), $(^{\circ}F)$ for vertical walls

1.5 Btu/hr. (ft^2), $(^{\circ}F)$ for the ceiling

0.5 Btu/hr. (ft^2), $(^{\circ}F)$ for the floor

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Although there may be some other values and other combinations of these values that might have resulted in a slightly better simulation than those used in this analysis, these three values can be considered representative design heat transfer coefficients in the underground cavities.

3) For larger shelters, the one-dimensional and compound model (M-(3)) will probably be adequate for calculating the shelter thermal environment. The complicated three-dimensional model, therefore, may not be required for the calculation simulating the 14-day occupancy of many large community shelters. For small shelters (such as family shelters similar to the NBS shelter), however, it is recommended that the three-dimensional model be used for the accurate calculation.

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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT 4212436

NBS REPORT 9473

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U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

TABLE OF CONTENTS

NOMENCLATURE

Unless otherwise defined in the text, the symbols used in this report are summarized, as follows:

Symbols		Dimensions
a	shelter dimension (half of the inside length)	ft
b	shelter dimension (half of the inside width)	ft
C_p	specific heat of moist air	Btu/lb, ^{o}F
c	shelter height	ft
d	shelter depth, distance between the earth surface and the ceiling of the shelter	ft
G	flow rate of ventilation air	CFM
h_g	ground surface heat transfer coefficient	Btu/hr, ft^2, ^{o}F
h_K or h	inner surface heat transfer coefficient of K th exposure	Btu/hr, ft^2, ^{o}F
k	thermal conductivity of solid	Btu/hr, ft, ^{o}F
L_E	Lewis Relation = $\frac{h_K}{\sigma C_p}$	dimensionless
Pvs	saturated vapor pressure of water at temp. t	inches Hg
Pv	vapor pressure of water in the air at dew point temperature	inches Hg
P_B	barometric pressure	inches, Hg
Q_{VS}	sensible heat released by the ventilation air	Btu/hr
Q_{VL}	latent heat released by the ventilation air	Btu/hr
Q_{GS}	sensible heat generated in the shelter by simulated occupants	Btu/hr
Q_{GL}	latent heat generated in the shelter by simulated occupants	Btu/hr
Q_{WSK}	sensible heat released by the shelter inner surface of K th exposure	Btu/hr
Q_{WLK}	latent heat released by the shelter inner surface of K th exposure	Btu/hr
Q_{MS}	sensible heat generated in the shelter by things other than simulated occupants	Btu/hr

Symbols		Dimensions
Q_{ML}	latent heat generated in the shelter by things other than simulated occupants	Btu/hr
Q_{SUN}	solar radiation intensity at the earth's surface	Btu/hr,ft^2
S_K	inner surface area of K th exposure	ft^2
t	temperature	^oF
W_a	humidity ratio	lb of water vapor/ lb dry air
W_s	humidity ratio of air saturated by water vapor	lb of water vapor/ lb of dry air
X_K (K = 1,6)	coordinate system used for shelter heat transfer	ft
$X_{K,O}$ (K = 1,6)	coordinates of the system boundaries	ft
α_K	thermal diffusivity of earth in the region surrounding K th exposure	ft^2/hr
η	albedo of earth surface	dimensionless
θ	time coordinate	hr
λ	latent heat of vaporization of water	Btu/lb
σ	water vapor transfer coefficient	(lb/(hr)(ft^2)(lb/lb dry air)
ρ	density of moist air	lb/ft^3
ΔX_K	finite difference length along X_K	ft
$\Delta\theta$	finite difference time	hr
Σ	summation symbol	

Subscripts

Unless otherwise stated, the following rules of subscripting will apply to all of the variables.

a shelter space properties

o outdoor air properties

Subscripts--continued

v	ventilation air properties
c	concrete property
g	ground surface properties
∞	deep underground
K	innersurface exposure index

$K = 1$ = North

2 = South

3 = East

4 = West

5 = Floor

6 = Roof

In some cases, the subscript W is used to denote the wall properties instead of K being 1, 2, 3, and 4.

The subscripts R and F are employed in the same manner, denoting, respectively, the properties pertaining to roof and floor regions.

S	sensible heat property
s	saturated air property
L	latent heat property

Operational Symbols

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

CAPTIONS FOR FIGURES

CAPTIONS FOR FIGURES (cont'd)

Fig. 11. Comparison of the calculated and observed shelter air temperatures and relative humidities for test 5 of NBS family shelter (computer program M-(2)).

Fig. 12. Comparison of the calculated and observed shelter air temperatures for summer condition test for Summerlin shelter (computer program M-(2)).

Fig. 13. Comparison of the calculated and observed shelter air relative humidities for summer condition test for Summerlin shelter (computer program M-(2)).

Fig. 14. Comparison of the calculated and observed earth temperatures surrounding Summerlin shelter during summer test conditions (computer program M-(2)).

Fig. 15. Comparison of the calculated and observed shelter air temperatures and relative humidities during moderate weather condition test for Summerlin shelter (computer program M-(2)).

Fig. 16. Comparison of the calculated and observed shelter air temperatures for Broyles shelter (computer program M-(2)).

Fig. 17. Comparison of the calculated and observed shelter relative humidities for Broyles shelter (computer program M-(2)).

Fig. 18. Comparison of the calculated and observed shelter air temperatures for Napier shelter (computer program M-(2)).

Fig. 19. Comparison of the calculated and observed shelter relative humidities for Napier shelter (computer program M-(2)).

Fig. 20. Comparison of the calculated and observed shelter air temperatures and relative humidities for Reading shelter (computer program M-(2)).

CAPTIONS FOR FIGURES (cont'd)

COMPARISON OF DIGITAL COMPUTER SIMULATIONS OF THERMAL ENVIRONMENT IN OCCUPIED UNDERGROUND PROTECTIVE STRUCTURES WITH OBSERVED CONDITIONS

By

T. Kusuda and P. R. Achenbach

1. INTRODUCTION

This report compares digital computer calculations of thermal environment for underground protective shelters with observed conditions of temperature and humidity. Several digital computer programs have been developed by the National Bureau of Standards for the purpose of simulating the heat transfer of underground structures. These computer programs were applied to 7 shelters, whose thermal environment under simulated conditions of occupation had been observed experimentally. Since the thermal environment in underground protective structures may become extremely unfavorable, particularly during the summer occupancy period, for large areas of the United States, the majority of prototype shelters mentioned herein were tested under summer climatic conditions. Of the 7 shelters whose thermal environments were calculated and compared with experimental observations, 12 different test conditions were included, 2 of which were under moderate winter conditions.

Analytical and experimental studies of various shelters have shown that the temperature and humidity within the occupied underground shelter depend on many parameters, which may be classified as follows:

1. <u>Structural characteristics</u>.
   a. Size and shape.
   b. Physical and thermal properties of construction material.

2. Site characteristics.

    a. Physical and thermal properties of earth surrounding the shelter.

    c. Thickness of earth cover.

    d. Type of earth surface and landscape.

    e. Neighboring buildings and installations.

3. Climatic factors.

    a. Earth temperature.

    b. Psychrometric condition of outdoor air.

    c. Solar radiation.

    d. Precipitation.

4. Operational characteristics.

    a. Ventilation rate.

    b. Psychrometric condition of ventilation air

    c. Density of Occupancy.

    d. Activity of Occupancy.

    e. Heat and moisture release by equipment in shelter.

    f. Emergency condition such as sealed up or surface fire conditions.

Testing of underground structures to cover even a small portion of all of the possible combinations of the above parameters is a formidable and expensive task. However, the number of tests could be drastically decreased, and the efficiency of testing improved, if the effect of various parameters in the thermal environment of a shelter could be predicted by computation. The mathematical formulation of such a computation should take into account a majority of the important parameters so the sensitivity of the overall thermal environment to the several parameters could be studied individually

or simultaneously with others. The mathematical procedures should be simple enough so the computation time (or computer cost) would be reasonable. Finally, and most important, the computed results should be reliable.

Some previous computations of the thermal environment in shelters have been reported which take into account simulated human metabolism, ventilation effects, and heat transfer in the earth [1,2,3], but there have been very few actual comparisons between calculations and observations for a given system over a substantial period of time. It is fortunate that the observed results of six of the seven shelters covered by this study were so well documented by reports of the University of Forida [4], thus making possible comprehensive comparisons between the calculated thermal environment and the observed results.

2. BASIC HEAT TRANSFER RELATIONS

Since the details of the numerical technique employed for the heat transfer of underground protective structures have been reported previously [1], only basic mathematical formulations employed for all of our computer programs are given here:

2.1. Shelter air heat balance.

$$\sum_{K=1}^{6} Q_{WSK} + Q_{VS} + Q_{GS} + Q_{MS} = 0$$

$$\sum_{K=1}^{6} Q_{WLK} + Q_{VL} + Q_{GL} + Q_{ML} = 0$$

where

$$Q_{WSK} = h_K(t_K - t_a)S_K$$

$$Q_{WLK} = \left(\frac{h_K \lambda}{C_p L_e}\right) (W_K - W_a) S_K \quad \text{for } W_s < W_a$$

$$= 0 \quad \text{for } W_s \geq W_a$$

$$Q_{VS} = (1.08)\ (G)\ (t_V - t_a)$$

$$Q_{VL} = (4.5)\ (G)\ (W_V - W_a)$$

Q_{GS} =	330	Btu/hr, person	60 °F
	300		70 °F
	220		80 °F
	115		90 °F
	0		100 °F
	-140		110 °F
	-280		120 °F

Q_{GL} =	70	Btu/hr, person	60 °F
	100		70 °F
	180		80 °F
	285		90 °F
	400		100 °F
	540		110 °F
	680		120 °F

2.2. <u>Shelter Inner Surfaces.</u>

$$Q_{WSK} + Q_{WLK} = -k_K \int_{S_K} \frac{\partial t}{\partial X_K}\, dS_K$$

2.3. <u>Concrete (or inner wall) heat conduction.</u>

$$\frac{\partial^2 t_c}{\partial X_K^2} = \frac{1}{\alpha_{CK}} \frac{\partial t_c}{\partial \theta}$$

2.4. Boundary between the concrete (or inner wall), and earth.

$$t_c = t_g$$

$$k_{CK} \frac{\partial t_c}{\partial X_K} = k_{CG} \frac{\partial t_g}{\partial X_K}$$

2.5. Earth heat conduction.

$$\frac{\partial t_g}{\partial \theta} = \alpha_g \nabla^2 t_g \text{ for three-dimensional model}$$

$$\frac{\partial t_g}{\partial \theta} = \alpha_g \frac{\partial^2 t_g}{\partial X_K^2}, \text{ K=1 to 6 for one-dimensional model}$$

2.6. Earth boundary conditions.

2.6.1 Four-wall region $\frac{\partial t_g}{\partial X_K} = 0$ at X_K = (some large distance)

K = 1, 2, 3, 4.

2.6.2 Floor region $t_g = t_{g_m}$ at X_K = (some large distance)

where K = 5

2.6.3 Roof region

where K = 6

Radiation model $-k \frac{\partial t_g}{\partial X_K} = h_g (t_g - t_o) + Q_{rad}$

(a) equilibrium model $t_g = t_o$

(b) adiabatic model $\frac{\partial t_g}{\partial X_K} = 0$

(c) solar-heat model

$Q_{rad} = (1 - \eta)\, Q_{sol}$ during the solar irradiation

$Q_{rad} = 0$ during no solar irradiation

This solar heat model is essentially the same as the sol-air temperature concept and ignores the direct radiation heat exchange between earth surface and sky, but it does include the effective radiation heat exchange between the earth surface and ambient air by adjusting the value of N_g. According to the last equation, however, the earth surface temperature never becomes lower than the air temperature, which is not always the case.

2.7. Psychrometric calculations.

Taking advantage of the large memory of the high speed digital computer of the National Bureau of Standards, all the psychrometric calculations were performed using the thermodynamic properties of moist air published by Goff and Gratch.

The thermodynamic properties of dry air and those of saturated air at one standard atmospheric pressure, such as the following, were tabulated as temperature functions by Goff and Gratch [5].

W_s = humidity ratio of the saturated moist air (lb/lb of dry air).

h_a = enthalpy of dry air (Btu/lb of dry air).

h_s = enthalpy of the saturated moist air (Btu/lb of dry air).

h_w = enthalpy of the water (Btu/lb of water).

V_a = volume of the dry air (cu ft/lb of dry air).

V_s = volume of the saturated moist air (cu ft/lb of dry air).

f_s = factors related to the relative humidity and degree (dimensionless) of saturation.

These properties were read into the computer for the temperature range from 30 °F to 120 °F at every one degree increment, except that the humidity ratio, W_s, was programmed for the temperature range from -20 °F to 120 °F at every one degree increment.

The following psychrometric symbols and formulas are used to derive the desired properties from given sets of properties, such as dry- and wet-bulb temperatures:

P_v = partial water vapor pressure in moist air (in. Hg).

P_B = barometric pressure (in. Hg).

P_{vs} = partial water vapor pressure in saturated air (in. Hg.).

φ = relative humidity, as a fraction

μ = degree of saturation.

W = humidity ratio of moist air (lb/lb of dry air).

V = volume of moist air (cu ft/lb of dry air).

W_s^* = W_s evaluated at the thermodynamic wet-bulb temperature (lb/lb of dry air).

h_w^* = h_w evaluated at the thermodynamic wet-bulb temperature (Btu/lb of water).

h_s^* = h_s evaluated at the thermodynamic wet-bulb temperature (Btu/lb of dry air).

$$W = 0.622 \frac{P_v}{P_B - P_v} \qquad 2.7\text{-}1$$

$$\varphi = \frac{P_v}{P_{vs}} \qquad 2.7\text{-}2$$

$$\mu = \frac{\varphi(1 - f_s \frac{P_v}{P_B})}{1 - \varphi f_s \frac{P_v}{P_B}} \qquad 2.7\text{-}3$$

$$W = \mu W_s \qquad 2.7\text{-}4$$

$$V = \mu(V_s - V_a) + V_a \qquad 2.7\text{-}5$$

$$h = \mu(h_s - h_a) + h_a \qquad 2.7\text{-}6$$

$$h + (W_s{*} - W)h_w{*} = h_s{*} \qquad 2.7\text{-}7$$

The last formula represents the thermodynamic wet-bulb temperature relation for given h and W of moist air.

The psychrometric calculations of thermal environment begin, usually, with input data for dry- and wet-bulb temperature of moist air. These two temperature data are sufficient to describe the complete thermodynamic state of the moist air at one standard atmosphere. The actual calculations involving heat- and mass-balance within a given thermal system are, however, more readily performed with the dry-bulb temperature and the humidity ratio, as seen in equations of shelter heat balance. The method used during this study to obtain the humidity ratio of moist air from its dry- and wet-bulb data is described as follows:

The thermodynamic wet-bulb temperature relation 2.7-7 can be expanded by the use of enthalpy expression 2.7-6.

$$\frac{W}{W_s(t)}\left[h_s(t) - h_a(t)\right] + h_a(t) + \left[W_s{*}(t') - W\right]h_w(t') = h_s{*}(t') \qquad 2.7\text{-}8$$

In the above expression, $W_s(t)$, $h_s(t)$, and $h_a(t)$ are thermodynamic properties at dry-bulb temperature t, while $W_s{*}(t')$, $h_s{*}(t')$, and $h_w{*}(t')$ are thermodynamic properties evaluated at wet-bulb temperature t'.

Rearranging the terms in equation 2.7-8, the humidity ratio W for dry- and wet-bulb temperatures t and t' can be expressed as

$$W = \frac{h_s{*}(t') - h_a(t) - h_w{*}(t')W_s{*}(t')}{h_s(t) - h_a(t) - h_w{*}(t')W_s(t)}\,W_s(t) \qquad 2.7\text{-}9$$

The calculation of the thermodynamic wet-bulb temperature from a given dry-bulb temperature and humidity ratio is also possible from

2.7-8 by an iterative technique. The iterative technique found successful during the course of this investigation is the inverse interpolation formula [6] of Newton applied to Goff and Gratch tables.

2.8. Effective temperature of shelter air.

For some of the shelter analyses, effective temperatures have been calculated from dry- and wet-bulb temperatures assuming an air velocity of less than 20 fpm. The effective temperature chart of the ASHVE* has been stored in the computer memory in a tabular format, and a table-searching and interpolative subroutine used to calculate the effective temperature.

3. DESCRIPTION OF COMPUTER PROGRAMS

3.1. Computer models.

Basically four different computer programs have been developed during this study. All the programs, however, essentially employ the time-iteration technique for solving transient heat conduction equations and they are designated as follows:

M-(1) Three-dimensional model with composite walls and with separate initial temperature pattern normal to the six boundary surfaces.

M-(2) Three-dimensional model with homogeneous heat conduction medium having separate initial temperature patterns normal to the six boundary surfaces.

M-(3) One-dimensional compound heat conduction model for composite regions treating the six exposures separately.

M-(4) One-dimensional compound heat conduction model for six composite regions assuming an adiabatic roof.

Each program has advantages and disadvantages, as discussed in the following pages.

* ASHVE Guide 1950 Chapter 6

M-(1). This program has been described in reference [2], and was used to evaluate the NBS family shelter. The earth temperature field surrounding the shelter was divided into 6 blocks, such as shown in figure 1. This block system enabled the program to account for situations in which some wall region(s) may be considerably different from the others in heat transfer properties and earth temperature.

The initial temperature in each block was programmed only in the direction normal to the wall surface, however, because the temperature profiles were usually known only along those directions.

Temperature calculations for the entire earth region surrounding the shelter were made with time-iterative techniques on three-dimensional finite difference equations. The concrete wall (including floor and ceiling) temperatures were calculated by one-dimensional finite difference equations separately for each wall, assuming that lateral temperature variation on the interior surface for a given wall could be neglected. Each inner wall-surface temperature was determined by surface heat balance equation 2.2, including vapor condensation but excluding condensate re-evaporation. The shelter psychrometric condition, dry-bulb temperature, dew-point temperature, and relative humidity were then evaluated, based upon the total heat balance equation 2.1.

M-(2). In this model, thermal properties or heat transfer characteristics around the shelter air space all were assumed homogeneous. In other words, no distinction in thermal properties was made from the concrete wall to the soil, or from one wall region to the other, as in Model M-(1).

The earth temperature initialization was performed only in the direction normal to the earth surface. The finite difference scheme employed for the three-dimensional time-iteration solution of the heat

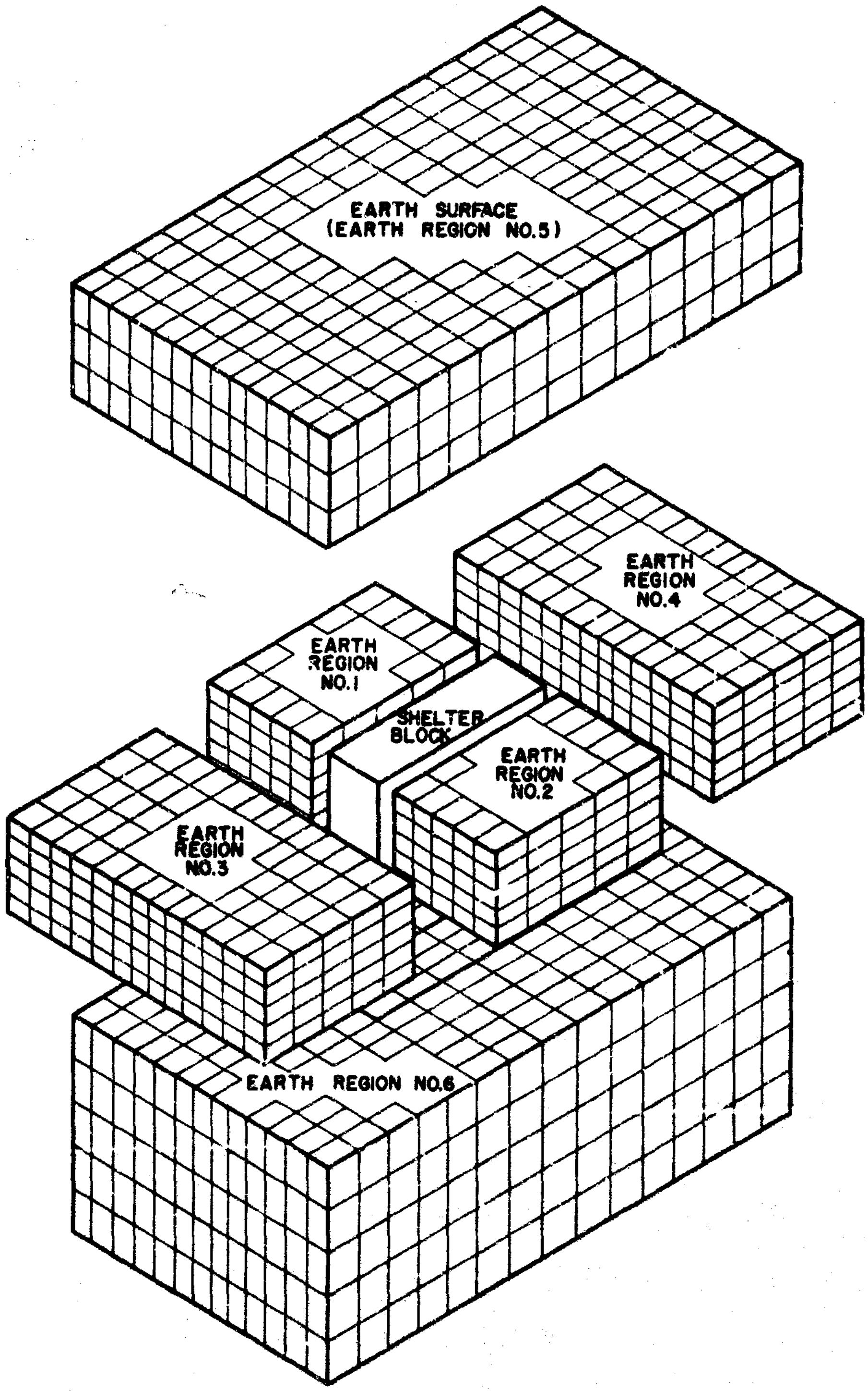

DIAGRAM OF HEAT TRANSFER MATRIX
AROUND FAMILY SHELTER
(SCHEMATIC)

Fig. 1 Schematic diagram of the matrix used for computer program M-(1).

conduction equation is shown in figure 2. The homogeneity assumption of the heat conduction equation mentioned makes it possible to analyze only a one-quarter segment of the shelter, because of the symmetric nature of the entire system. The details of this program have been described in reference [1]. This program was applied to the NBS 6-man family shelter, the Summerlin shelter, the Broyles shelter, the Napier shelter, and the Reading shelter, for the purpose of comparing the calculated shelter thermal environment with the experimentally observed data.

M-(3). The three-dimensional effect on earth heat conduction around the shelter becomes less and less significant as the shelter size increases. A one-dimensional compound system was developed primarily for large shelters, where a major portion of the heat flow is always normal to the shelter walls, ceiling, and floor. This program is identical with M-(1), except that the corner region of earth and concrete is ignored, and the one-dimensional finite difference equation was used for earth temperature determinations. Comparison with the two previous programs indicates that the earth temperature computation scheme was drastically simplified in the model. The program was applied to the Summerlin and Reading shelters.

M-(4). This program was a modification of M-(3), to simulate basement type shelters such as the two at Ft. Belvoir. The heat transfer in the ceiling region of basement shelters will be much less significant than that in wall and floor regions. Thus, in this program, the outer face of the ceiling layer was assumed adiabatic.

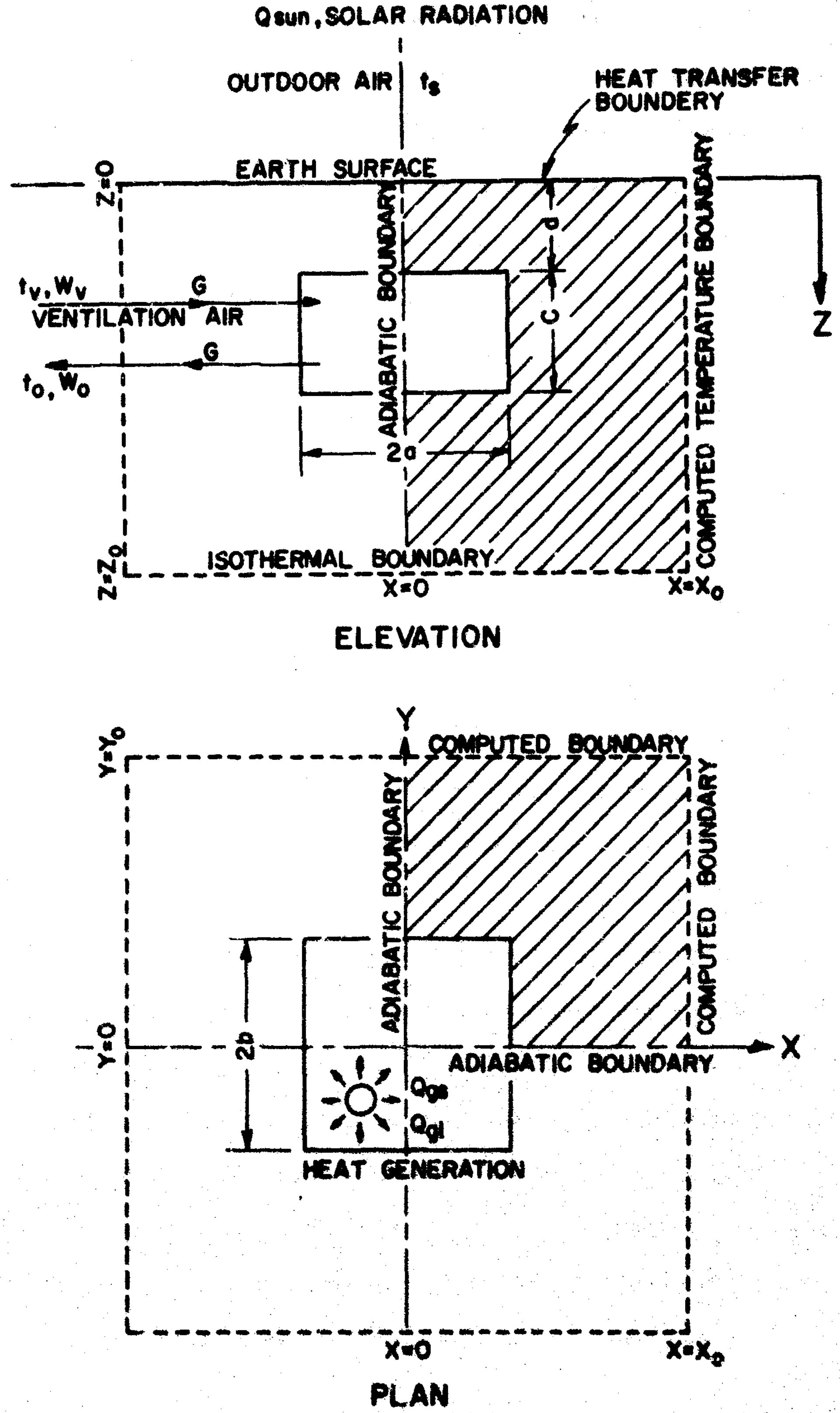

Fig. 2 Schematic diagram of the heat conduction region used for computer program M-(2).

The calculation of the psychrometric condition of shelter air for this program was designed so that dry- and wet-bulb and dew-point temperature, as well as shelter effective temperature, can be computed with or without the air conditioning system turned on. The details of the air conditioning calculations used in this program are described in the appendix. This program was applied to 200-man and 1000-man shelters of Ft. Belvoir, which were tested by the University of Florida.

3.2. Initialization of earth temperature surrounding a protective shelter.

Accurate heat transfer calculations for the early part of an occupancy period for these shelters are extremely difficult, because of the uncertainty about the earth temperature distribution around the shelter. Particularly for the shelters that had been installed wich only a shallow earth cover, the temperature variation from roof region to the floor region, from one wall region to another, and from corner to flat surface region was quite appreciable, and very complex to approximate mathematically.

In order to simulate this complex and three-dimensional pattern of the initial earth temperature around the shelter, assuming that such three-dimensional patterns are important, the earth temperature program becomes highly, and perhaps unnecessarily, complicated. Therefore, during the study, a simplification was made by selecting three initial temperature patterns, as follows:

-1. Earth temperature gradients are always in a direction normal to four walls, floor, and roof surfaces - block mode.

I-2. Predominant earth temperature gradient is always along a vertical path, from the surface downward - vertical mode.

I-3. Earth temperature is virtually constant all around the shelter - constant mode.

These three modes of the initial earth temperature patterns have been employed during the calculation, and presented in this report.

However, it is important to remember that the detailed earth temperature profile data surrounding shelters seldom will be available, even when it is important, for the majority of actual shelters. For most of the thermal environment calculations of underground structures, it is usually assumed that the earth has a single value of temperature. This uncertainty in the initial earth temperatures is one of the sources of error in predicting the thermal environment of shelters, particularly for the early period of shelter occupancy.

4. DESCRIPTION OF PROTOTYPE SHELTERS

Brief descriptions of the prototype shelters used for this analysis and their characteristics are given. If the mathematical simulation of shelter thermal environment is to be most effective, it is necessary to secure accurate information regarding many parameters related to structural, site, climatic, and operational characteristics of shelters.

4.1. NBS shelter.

The family size shelter in Washington, D. C., tested by the National Bureau of Standards, was constructed according to Bulletin MP-15

of the Office of Civil Defense [3] with some small modifications. It was a concrete wall shelter with external dimensions of 12 feet long, 9 feet 4 inches wide, and 7 feet 6 inches high (not including hatch), placed in an excavation and covered with 2 feet 3 inches of earth. The interior dimensions of the shelter area were 10 feet 8 inches long, 8 feet wide, and 6 feet 6 inches high. A 2-foot-wide hatchway was installed on the north side of the occupancy area and separated from the 8- by 8-foot living space by an 8-inch-thick concrete shielding wall. The earth surface over the shelter was grass covered and partially in the shade of neighboring trees. The soil around the shelter was mostly loam and clay; its density averaged about 109 lb/ft^3, and its moisture content averaged about 15 percent (dry weight basis).

Ventilation air was controlled in a neighboring equipment house to specified conditions and ducted into the shelter through an inlet at the mid-height of the shielding wall facing the occupied area, and the shelter air was exhausted through an outlet located on the opposite wall of the hatchway.

Six simulated occupants (SIMOC) were carefully designed and constructed to produce sensible and latent portions of metabolic heat as functions of shelter area temperature (details of SIMOC are found in reference [3]). Four SIMOC's had a nominal heat output of 400 Btu/hr, and the other two had heat outputs of 200 and 600 Btu/hr, respectively.

Complete psychrometric observations were made at the ventilation air inlet, the exhaust air outlet, and at the 5-foot level above the

geometrical center of the shelter floor. Temperature observations obtained during this test included earth temperatures around the shelter to a maximum distance of 4 feet away from the exterior surface of the concrete wall for all four walls and the floor. In the shelter roof region, earth temperature was studied with four thermocouples located 6 inches, 12 inches, 18 inches, and 24 inches from the external surface of the shelter ceiling.

Five tests were conducted with variations in test duration, ventilation rate, number of occupants, ventilation air condition, and surrounding earth temperature. Test 1 was conducted with no occupants, with 42 cfm of ventilation air. Tests 2, 3, and 4 were each conducted with six SIMOC's, and with ventilation air rates of 0, 18, and 42 cfm, respectively. Test 5 was undertaken to simulate winter conditions of occupancy, ventilation air, and earth temperature, using six SIMOC's and 18 cfm ventilation air.

4.2. Summerlin shelter [4].

This shelter was a welded steel structure located entirely below the finished grade line, with a 30-inch earth cover over the roof, in a rural area of Gainesville, Fla., and thermally isolated from other buildings. The occupancy area dimensions were 23 feet 7 inches long, and 7 feet 8 inches wide. The shelter roof was arched over the wall, and the maximum ceiling height at the middle of the arch was 7 feet 2½ inches. A 4- by 3-foot hatchway was located at one end of the shelter. The earth around the shelter was a mixture of sand and loam, and the earth cover was bare at the time of the shelter environmental tests. The moisture content (dry weight basis) of the soil samples analyzed ranged from 9 percent to 19 percent; their dry density ranged from 103 lb/ft^3 to 111 lb/ft^3.

Ventilation air conditions were generated in an equipment trailer located outside the shelter, and supplied to the shelter by a flexible tube passing through the entrance hatch. The ventilation air inlet was near the north end of the shelter, and shelter air was exhausted from a stack located at the southeast corner.

Two series of environmental tests were conducted, using 18 SIMOC's (ref. 3) of NBS 400 Btu/hr type; one during July 1962 with ventilation air of 200 cfm and typical Florida summer outdoor psychrometric conditions; and the other during April 1963 with ventilation rates of 54 and 216 cfm at August and April psychrometric conditions. The simulated August psychrometric conditions used for the tests were diurnal cycles of 96 °F maximum dry-bulb temperature, 80 °F minimum dry-bulb temperature, and 79.8 °F average dewpoint temperature. The simulated April psychrometric conditions used for the test were diurnal cycles of 76 °F maximum dry-bulb temperature, 61 °F minimum dry-bulb temperature, and 59.5 °F average dewpoint temperature.

4.3. The Broyles shelter [4].

The Broyles Shelter, at Gainesville, Fla., was so constructed that a portion of the shelter was below grade, and 3 feet of earth was mounded around the above-grade portion. The interior of the shelter had a ceiling height of 7.33 feet, and the floor area measured 16 by 7.75 feet, for a total area of 124 square feet. The floor, placed on a plastic membrane, was of waterproof concrete reinforced with 1/2-inch steel rods on 12-inch centers. The walls were hollow concrete blocks with conventional mortar joints, and the cavities were filled with waterproof cement as the walls were constructed. The roof was a concrete slab reinforced with 3/8-inch

steal rods on 12-inch centers. The concrete was treated with a waterproofing material at the time it was mixed. This shelter was shaded by surrounding trees, and a heavy layer of sod and green grass covered it and the surrounding ground. The surrounding earth was a mixture of sand and loam, whose dry density ranged from 95 lb/ft^3 to 104 lb/ft^3, and moisture content from 1 percent to 12.5 percent.

For most of the thermal environment test period, 1[illegible] SIMOC's (ref. 3) of NBS 400 Btu/hr type were employed. The ventilation air was processed outside the shelter to simulate diurnal cyclic conditions of 96 °F maximum dry-bulb temperature, 80 °F minimum dry-bulb temperature, and 70 °F average dew-point temperature, and was forced into the shelter by a fan through an air supply duct that was laid along the inside surface of the longitudinal shelter wall, and which had four equally spaced outlets. The shelter air was exhausted through two outlets located at opposite ends of the shelter.

In addition to the regular psychrometric measurements of inlet ventilation air, shelter exhaust air, and shelter air at the geometrical center, several measurements were made of the shelter inner wall surface temperature and surrounding earth temperature.

The shelter was tested in four successive phases:

Phase 1: A ventilation rate of 3 cfm per person was supplied, and a fan-and-coil unit simultaneously cooled the recirculated air by 4 gpm of well water at an inlet water temperature of 71.5 °F. During the first two days, sensible and latent heat was removed from the shelter by this fan-and-coil unit at a rate of 6440 Btu/hr. This cooling capacity exceeded the total heat supplied to the SIMOC's by 4800 Btu/hr.

Phase 2. The well-water coil was cut off and 10 cfm per person of ventilation air was supplied for a period of 12 days.

Phases 3 and 4. These two phases were operated under the same conditions as phase 2, except that the ventilation rate in phase 3 was 6 cfm per person (for 48 hours) and in phase 4 was 3 cfm per person (for 48 hours).

4.4. Napier shelter [4].

The Napier shelter was a 100-occupant community shelter designed for a group of residents in a subdivision adjoining the city of Gainesville, Fla. The floor level was 5 feet below grade and 30 inches of earth covered the roof. The floor slab was wire-mesh reinforced, 4-inch-thick concrete poured over a waterproof plastic membrane. The walls were of 8-inch-thick hollow concrete blocks, whose cavities had reinforcing rods placed vertically through then at selected intervals and were then filled with concrete. Outside dimensions were 20 feet wide and 85 feet long. The interior floor area was 1561 square feet. Reinforced prestressed concrete T-beams placed on top of the shelter walls, each in contact with the beams parallel to it, formed its roof. The surrounding earth was mostly clay, whose dry density varied from 76 lb/ft^3 to 109 lb/ft^3, while the moisture content ranged from 3.4 percent to 34.2 percent (dry weight basis). The earth surface over the shelter was bare with several patches of weeds.

For this test, 100 SIMOC's (ref. 3) of NBS 400 Btu/hr type were employed. The ventilation air was conditioned in the equipment trailer outside the shelter to represent a diurnal cycle of a Florida summer: 96 °F maximum dry-bulb temperature, 80 °F minimum dry-bulb temperature,

and 73 °F average dewpoint temperature. It was forced into the shelter at two stations at the ceiling level in the south wall, approximately 8 feet from the southwest and southeast corners of the shelter. The ventilation air was discharged in the direction of the north wall; and after passing through the main chamber was exhausted through the entry doorway and entry chamber. Regular psychrometric measurements were made of shelter air, ventilation air, and exhaust air. In order to study the three-dimensional earth temperature profile during the simulated occupancy period of the shelter, numerous measurements of earth temperature were made around the northwest and southwest corner regions.

The test was conducted in six phases:

Phase 1. Ventilation rate was maintained at 3 cfm per person for 48 hours, during which a well-water coil using 12 gpm of 72.2 °F water was in operation. The measured total cooling capacity of the well-water coil during the phase averaged 20,700 Btu/hr, amounting to 51.6 percent of the total heat released by SIMOC's.

Phase 2. Ventilation air rate was increased to 6 cfm per person and the well water coil was shut off for this period of 97 hours.

Phase 3. With all other conditions being identical with those of phase 2, 30 NBS SIMOC's were replaced by one MASS SIMOC of MRD [4] for 42 hours. (One MASS SIMOC has an adjustable output from 1-40 SIMOC's of NBS 400 Btu/hr type.)

Phase 4. The MASS SIMOC was replaced by 30 NBS SIMOC's for 51 hours.

Phase 5. Ventilation air rate was increased to 8.05 cfm per person with 100 NBS SIMOC's for 116 hours.

Phase 6. The total ventilation rate remained at 805 cfm and 100 NBS SIMOC's were used together with 1 MASS SIMOC for 36 hours, representing a total of 140 occupants.

4.5. Reading shelter [4].

This was a community shelter located in a park owned by the city of Reading, Pa. It was constructed in a hillside to take advantage of a thick earth cover, and was basically a rectangular parallepiped 56 feet long, 17 feet 4 inches wide, with a ceiling height of 7 feet 8 inches. The ends of the shelter were connected to separate tunnel-like entry corridors so that two right angle turns were formed in each of these passageways. The floor was 4 feet 6 inches below the grade level that existed prior to construction, and the roof and all sides had a minimum earth covering of 30 inches. All bearing walls, the roof, and the floor were constructed of concrete reinforced with steel bars. Waterproofing was applied to the external surfaces of the shelter during construction. There were many internal partition walls constructed of hollow concrete blocks with mortar filled voids, for rooms of various purposes, such as storage, first aid, mechanical equipment, and lavatory. The surrounding earth was sandy loam of dry density between 89 lb/ft^3 and 121 lb/ft^3, and moisture content between 10 percent and 22 percent (dry weight basis). The earth surface at the time of testing was grass under snow. Ventilation air artificially created in an equipment trailer outside the shelter was carried to the shelter through a duct connected to a stack that under normal shelter operation would be utilized as an exhaust stack. A temporary distribution duct for ventilation air supply was installed at the ceiling level along the west wall of the shelter.

Three air outlets were installed in the temporary duct at equally spaced intervals. The air was exhausted through a stack located in the center of the ceiling of the equipment room, which was almost longitudinally at the opposite end from the air supply duct.

The ventilation air conditions used for this test varied considerably; however, the dry-bulb temperature was generally maintained between 32 and 40 $^{\circ}$F, with an average dewpoint temperature of 30 $^{\circ}$F. The simulated occupants used were two MASS SIMOC's (ref 4), which were capable of producing sensible and latent metabolic heat equivalent to 120 sedentary adults.

Psychrometric observation stations were located at the ventilation air inlet, geometric center of the shelter, and exhaust air outlet. Thermocouples were used to measure interior surface temperatures and several ground temperatures extending downward 45 inches distance from the top of the floor slab and horizontally from the outside surface of the west wall. The roof region ground temperature was also measured at several distances from the outside surface.

The test was divided into seven phases, described as follows:

Phase 1. Ventilation at the rate of 150 cfm was supplied to the shelter in the manner described previously, and the two MASS SIMOC's were adjusted to deliver heat and moisture equivalent to a total of 50 sedentary adults. This phase continued from February 26 to March 4, 1963.

Phase 2. Ventilation rate was then decreased to 75 cfm, or 1.5 cfm per person, with operating conditions identical to those of phase 1. This phase lasted approximately 5 days.

Phase 3. The mass SIMOC's were readjusted to produce total equivalent metabolic heat for 100 occupants. The total ventilation air rate was 150 cfm during this phase of study, lasting three days.

Phase 4. During the three-day period that followed phase 3, from March 12 to 14, shelter occupancy was 50 simulated occupants. The ventilation air at a rate of 831 cfm was supplied by the blower that originally had been installed in the shelter as a part of the permanent facilities. The shelter's own air handling systems provided the distribution and exhaust of the shelter air. The purpose of this phase of the test was to determine if the original equipment for supplying air, and the air distribution and venting systems were adequate.

Phase 5. During this phase, ventilation air at the rate of 718 cfm was supplied for 50 simulated occupants. The air distribution and exhaust systems were changed during this phase, details of which are not important for the purpose of this report.

Phases 6 & 7. These phases were conducted for sealed-up conditions without ventilation for 50 simulated occupants for 24 hours, and 100 cimulated occupants for 58 hours, respectively.

4.6. Ft. Belvoir 200-man shelter.

This was an experimental 200-man shelter designed and built by the Protective Structures Development Center at Ft. Belvoir, Va. It was a two-story reinforced concrete structure with one story below ground level. Because the building had been occupied by personnel of the Protective Structures Development Center prior to the environmental testing, the temperature and humidity had been comfort conditioned. Only the basement area was used for the shelter environment test, while the upper

floor area was heated to simulate an adiabatic roof condition. The shelter walls were 10 inches thick, the floor slab 6 inches thick, and the ceiling-floor slab 8 inches thick. There was a 12-inch-thick fill of gravel between the external surface of concrete of the basement and the earth on all sides, except the north end. The earth around the shelter was a mixture of sand and clay, its dry density varying from 85 lb/ft^3 to 120 lb/ft^3 and its moisture content from 9 percent to 23 percent (dry weight basis). The earth surface was composed of sod on all sides of the shelter, except for a portion of the north end where a bituminous concrete driveway was located. Interior dimensions were 37 feet 2 inches by 37 feet 2 inches, with a ceiling height of 9 feet 6 inches. Excluding a first aid room and stairwell, a net usable floor area of 1032 square feet was available for 100 simulated occupants. There were two family-type basement shelters that were built for display purposes in the test room, one of sand-filled concrete block walls and the other a triangular-shaped wooden lean-to filled with sand and sand bags. They may have had a considerable effect in absorbing heat during the first few days of the environmental test.

The temperature- and humidity-controlled ventilation air (dry-bulb cycles 93 °F ~ 76 °F and wet-bulb 78 °F ~ 74 °F were in phase with maximum at 2 p.m. and minimum at 4 a.m.) was produced in the equipment trailer parked outside the shelter and introduced into the shelter from ceiling level near the center of the occupied space. The exhaust outlet was also in the ceiling, approximately 12 feet from the air inlet. The thermal environment of the lower shelter space was measured with 100 SIMOC's of the NBS type (ref. 3).

The test was conducted in five phases, in which the ventilation air rates were 3 cfm per person for the first phase (6 days), 6 cfm per person for the second phase (2 days), 9 cfm per person for the third phase (3 days), 18 cfm per person for the fourth phase (2 days), and 27 cfm per person for the fifth phase (4½ days).

Psychrometric measurements were made at the ventilation air inlet, air exhaust, east geometric center, and west geometric center of the shelter. Temperature measurements were obtained of various inner surfaces, together with surrounding earth temperatures to a distance of 4 feet from the external surface of the concrete structure.

4.7. Ft. Belvoir 1000-man shelter.

This shelter was built by the Protective Structures Development Center at Ft. Belvoir, Va. It was a two-story reinforced concrete building with one story below ground level. Prior to testing the building had been occupied by personnel of the Protective Structures Development Center, and its thermal environment had been controlled at a comfort air condition by a central heating and cooling plant. Only the basement area was used for test, while the upper floor level was heated to simulate an adiabatic roof condition. The usable floor area of the basement was 5400 ft^2 and was given a simulated occupancy of 11 MASS SIMOC's (ref. 4). The shelter walls were 10 inches thick, the floor 6 inches thick, and the ceiling-floor slab 8½ inches thick. The interior dimensions were 74 feet 4 inches by 74 feet 4 inches, with a ceiling height of 9 feet 6 inches. The surrounding earth was sandy clay and ranged in moisture content from 10 to 20 percent (dry weight basis), and in dry density from 86 lb/ft^3 to 104 lb/ft^3 depending upon the depth, as well as upon

the location around the shelter. During the backfilling and mounding operations, a 12-inch-thick fill of gravel was placed adjacent to all the basement walls.

The ventilation air was conditioned by the equipment trailer to yield a local design diurnal cycle of dry-bulb temperature, 94 °F maximum, 76 °F minimum, and wet-bulb temperature, 78 °F maximum, 74 °F minimum. The maximum and minimum conditions of dry- and wet-bulb temperatures were both at 2 p.m. and 4 a.m., respectively. The ventilation air inlet and exhaust air outlet were both near a corner of the space and separated from each other by approximately 12 feet for most of the test period.

The test was divided into four major phases, excluding an initial short period of purging. Phase 1 was a sealed-up-condition test of approximately 8 hours without ventilation, whereas the ventilation rates for remaining phases were varied from 16.8 cfm per person for 3½ days, to 5 cfm per person for 1 day. The shelter thermal environment was measured by dry- and wet-bulb thermometers at the exhaust duct, the northeast area, the southwest area, and the geometric center of the shelter, and numerous thermocouple temperature readings were taken for many parts of the wall surface and the earth region extending outward normally to the walls and floor to a distance of 4 feet from the exterior surfaces.

5. SHELTER CALCULATIONS

As discussed in section 2 of this report, the calculated shelter thermal environment is affected by several parameters, such as thermal conductivity and thermal diffusivity of surrounding walls and earth,

and heat transfer coefficients along the inner surfaces of the shelter and the ground surface. Based upon the characteristics of prototype shelters and their test conditions described in the previous section, table 1 is prepared to summarize the parameters used for the shelter calculations. However, many of the heat transfer parameters selected for the computation cannot be too precise. The following considerations were given for assigning numerical values to the parameters listed in table 1.

5.1. Physical dimensions (size and heat transfer area).

The size of the shelter is expressed in the overall internal dimensions, which are the overall external dimensions less the thickness of walls, ceiling, and floor. The heat transfer area used for the computation was calculated from the internal dimension only, thus ignoring the complex pattern of partitioning and, consequently, the heat absorption by partition walls or columns.

5.2. Simulated occupants.

The simulated occupants (SIMOC's) used for the experiment were designed to simulate the heat output of human bodies and each generated a total heat of 400 Btu/hr, regardless of temperature. The sensible heat component was regulated according to the shelter air temperature in the manner described in section 2. The number of active SIMOC's was varied during some tests (Napier and Reading shelters) by turning the power off and on to a part of them. For this reason, the area per person data shown in table 1 for these tests are not constant.

In order to simulate the change in number of SIMOC's during some of the tests, the NBS computer program was constructed to take the number of occupants as a time variable instead of a constant.

Table 1. UNDERGROUND FALLOUT SHELTER CALCULATIONS

Summary of Results As of February 1965

Tested Shelters	NBS Shelter, Washington, D. C. Test Conditions 1	2	3	4	5	Summerlin, Fla. Summer	Winter	Broyles, Fla.	Napier, Fla.	Reading, Pa.	Ft. Belvoir, Virginia 200-man	Ft. Belvoir, Virginia 1000-man
Size, ft.	10.7 x 8 x 6.5					24x7.7x7		16x7.8x7.33	83.7x18.7x7.7	55x16x7.66	37.17x37.17x9.5	74.33x74.33x9.50
400 Btu equiv. SIMOCS	0	6	6	6	6	18		12	100 ~ 140	50 - 100	100	540
Floor Area Ft^2/Person	-	14.3				10.3		10.7	15.6 ~ 11.1	17.6 ~ 8.8	13.8	10.2
Total Surface Ft^2/Person	69					65		50	46.8 ~ 33.4	57 ~ 28.5	41.8	25.7
Ventilation CFM/Person	(Total) 62 CFM)	2	7	3	3	11.1	3 ~ 12	3 ~ 10	3 ~ 8.4	1.5 ~ 3	3 ~ 27	5 ~ 16.7
Soil Type	Loam-Clay					Sand-Loam		Sand	Clay	Clay	Sand-Clay	Sand
Density: lbs/ft^3	92 ~ 115					103 ~ 128		99 ~ 104	76 ~ 109	89 ~ 122	90 ~ 110	86 ~ 104
Water Cont., % D. Wt.	14 ~ 21					10 ~ 20		1 ~ 12	34 ~ 34	10 ~ 22	10 ~ 24	10 ~ 21
*Average Outdoor Air Temp., °F	82	80	67	75~55	55	82	65	85	82	6 ~ 40	~ 60	~ 85
Initial Earth Temp., °F	69	70	69	67	65	81	70	83	80	36	74 ~ 68	72 ~ 69
*Ventilation Air Avg. DB, °F	80	--	82	82	46	87	75	86	87	32 ~ 40	93 ~ 78	93 ~ 78
Avg. DP, °F	66	--	68	69	33	72	55	70	73	30	~ 73	~ 70
/Assumed Parameters:												
α Ft^2/hr	0.026	0.026	0.022	0.022	0.030	0.022		0.029	0.025	0.022	0.02	0.02
k Btu/hr, ft, °F	0.75	0.75	0.75	0.75	0.75	0.75		0.65	0.75	0.75	0.75	0.75
H_w Btu/hr, ft^2, °F	0.45 ~1.6	0.45 ~1.6	1.0	1.0	1.0	1.0		1.0	1.0	1.21	1.0	1.0
H_R Btu/hr, ft^2, °F	1.4	1.4	1.5	1.5	1.5	1.5		1.5	1.5	1.43	1.5	1.5
H_F Btu/hr, ft^2, °F	0.35	0.35	0.30	0.30	0.3	0.3		1.0	1.0	0.57	0.5	0.5
Computer Model #	1	1	1 & 2	1 & 2	1 & 2	2 & 3	2 & 3	2	2	2 & 3	4	4

/ α = Thermal diffusivity of soil
k = Thermal conductivity of soil
H_w = Wall surface heat transfer coefficient
H_R = Ceiling surface heat transfer coefficient
H_F = Floor surface heat transfer coefficient
* Approximate average for the test period

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5.3. Ventilation air.

Observed hourly data on dry-bulb and dewpoint temperatures or dry-bulb and wet-bulb temperatures of the supply air duct were used as the input data, either in the 2-hour step or the 4-hour step calculations. Since the University of Florida varied the ventilation air rate during their tests, the computer program was designed to accept the ventilation rate as time dependent input data. These variations of the number of SIMOC's and ventilation rates during the tests are the reason that the per capita ventilation rate indicated in table 1 was not a constant for some of the tests.

The ventilation air temperature and humidity conditions were varied with respect to time, closely following a prescribed diurnal cyclic pattern in most cases. The entries in table 1 show approximate ranges of the temperature levels employed during the test, whereas actual hourly values were used in the calculations.

5.4. Thermal properties of earth and wall.

For all of the prototype shelters, soil samples were taken from several representative spots around the shelter at selected depths and were analyzed with respect to soil classification, dry density, and water content (dry weight basis); their typical characteristics are shown in table 1. The thermal conductivities and diffusivities of various types of soils are usually presented as functions of moisture content [5,6]. Such charts were consulted in arriving at the values of thermal conductivity, k, and thermal diffusivity, α, in table 1.

For the NBS shelter, the thermal diffusivity value of 0.026 ft^2/hr. for tests 1 and 2 was estimated from a phase angle shift of the earth temperature cycles at two different depths. The diffusivity values of

0.022 ft^2/hr for tests 3 and 4, and 0.03 ft^2/hr for test 5 were evaluated by a numerical technique similar to that reported by Beck [7]. The method is basically a reversed use of finite difference solutions of the heat conduction equation for a semi-infinite solid. For the case of composite wall models, the thermal diffusivity and conductivity of concrete were assumed as 0.036 ft^2/hr and 1.1 Btu/hr ft^2(deg F/ft), respectively.

5.5. Surface Heat Transfer Coefficients.

The surface heat transfer coefficient consists of a radiative portion and a convective portion. For the heat transfer at the interior shelter surfaces, the radiation portion plays a predominant role, since the air velocity over the shelter inner surface usually is very small. In addition, the surface heat transfer coefficient along any one of the vertical walls at a given time would vary considerably from the bottom to the top, due to the varying nature of layer pattern, as well as that of the radiation heat exchange geometry and air velocity, and also because of the difference in local temperature distribution. However, it is probable that the local variation of the surface heat transfer coefficient along a given surface may be of the same order of magnitude as the convective heat transfer coefficient itself. Several attempts were made during this study to obtain the surface heat transfer coefficients for the experimental observations of the shelter wall heat conduction. Since the NBS test shelter was equipped with a heat flow meter at the geometric center of each of all the inner surfaces, and since the inner surface temperatures and shelter air temperatures were simultaneously measured, it was possible to calculate the heat transfer coefficients. However, the accuracy of this procedure is questionable, because (a) the heat flow meter reading

at the geometric center of an inner surface did not necessarily yield an average heat transfer coefficient for the entire surface, because of the local variation of heat flow, and (b) where condensation of shelter air moisture was taking place simultaneously, the heat flow meter would read the total heat flux, which is not proportional to the temperature difference between the surface and air. In fact, these difficulties were realized in the NBS shelter, since the ratio agreement between the shelter total heat conduction estimated by the heat balance, and the heat conduction based upon the heat flow meter ranged from 52 percent to 108 percent in various tests [2].

Nevertheless, the values of heat transfer coefficients listed for the NBS shelter tests 1, 2, 3, and 4, and the Summerlin shelter test were estimated from the test 3 data of the heat flow meter readings, adjusted by the vapor transfer due to the difference of air humidity ratio between the air and the wet surface, and the Lewis relation of heat and mass transfer.

A low value for the floor coefficient was observed. This result was to be expected since the floor surface was typically colder than the air immediately above it and the downward connection heat transfer rate would be very low under these conditions. Moreover the effective heat transfer area of the floor was considerably reduced by the presence of simulated occupants. The same values for the surface coefficient were applied to the test 5 condition of the NBS shelter, but the agreement between the observed and calculated inner surface temperatures was rather poor when this low value of the surface coefficient was used.

Several other combinations of the surface heat transfer coefficients for NBS test 5 were tried and the results are summarized in table 2, which will be elaborated later in this section. For the many other prototype shelters, heat flow meter readings were not included, or were not usable, so that the detailed heat transfer analysis on the surface by surface basis was discarded. However, the average heat transfer coefficients for the entire inner surface were obtained from the sensible heat balance calculation for the Summerlin shelter during the moderate weather condition test, the NBS test 3, the NBS test 5, the Ft. Belvior 1000-man shelter, and the Napier shelter.

As indicated in figures 3 and 4, the result of this analysis on the overall sensible inner surface heat transfer coefficient shows a greatly fluctuating pattern. The accuracy of the calculated values of the surface heat transfer coefficient is inherently related to the accuracy of measuring air and surface temperatures. Since radiation would usually be present and wetted surfaces are sometimes involved, the error in temperature measurement could easily be a signigicant part of the observed temperature difference for differences of 2 $^{\circ}$F or less. A significant trend can be observed, however, from Figure 3 and 4 that the overall inner surface sensible heat transfer coefficient seems to increase as the temperature difference between the air and inner surface decreases. The majority of the sensible heat transfer coefficients are in the neighborhood of 1.0, except for the Napier shelter. Nevertheless, the inner surface heat transfer coefficients selected for the Proyles and Napier shelters of table 1 are somewhat arbitrary, whereas those given to the Reading and Ft. Belvior shelters are estimated from ref. 8, which was not available prior to the last three shelter calculations. The possible effects of the various

Table 2. EFFECT OF INNER SURFACE HEAT CONDUCTANCE FOR NBS SHELTER TEST 5

	Inner Surface Conductance			t_{wall}		t_{roof}		t_{floor}		t_{air}		R.H.		WG
	h_W	h_R	h_F	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	
7 days	2.0	1.0	2.5	55.0	54.23	56.6	55.82	54.5	55.21	58.8	56.97	90.0	77.61	0.
	2.0	1.0	2.0		55.28		56.60		56.06		58.01		75.12	0.
	1.0	1.5	1.0		55.74		58.23		56.87		60.38		72.28	0.
	1.0	1.5	0.5		56.45		58.79		56.46		61.22		85.89	0.
	1.0	1.0	1.5		55.79		57.96		57.43		60.38		72.27	0.
	2.5	1.0	2.5		54.06		55.49		54.78		56.36		79.32	0.
	2.5	1.0	2.5		56.54		58.97		56.78		58.76		74.22	1.0
	1.21	1.43	0.57		55.99		58.16		56.04		60.23		72.45	0.
	1.0	1.5	0.30		56.62		59.03		55.94		61.55		85.43	0.
14 days	2.0	1.0	2.5	59.0	55.69	59.8	55.18	57.3	56.75	62.3	58.22	88.5	76.27	0.
	2.0	1.0	2.0		56.61		55.87		57.56		59.13		75.10	0.
	1.0	1.5	1.0		57.21		57.81		58.46		61.35		72.34	0.
	1.0	1.5	0.5		57.47		58.15		57.87		61.81		71.78	0.
	1.0	1.0	1.5		57.29		57.23		58.98		61.48		72.19	0.
	2.5	1.0	2.5		55.41		54.78		56.29		57.58		77.05	0.
	2.5	1.0	2.5		58.67		59.71		58.91		60.73		73.11	1.0
	1.21	1.43	0.57		57.33		57.64		57.68		61.13		72.62	0.
	1.0	1.5	0.30		57.64		58.37		57.33		62.09		71.43	0.

Thermal Conductivity $k = 0.75$ Btu/hr, ft. °F, thermal diffusivity $\alpha = 0.03$ ft^2/hr

Earth Surface Heat Transfer Coefficient, $h_G = 5.0$ Btu/hr ft^2 °F

Lewis Relation = 1

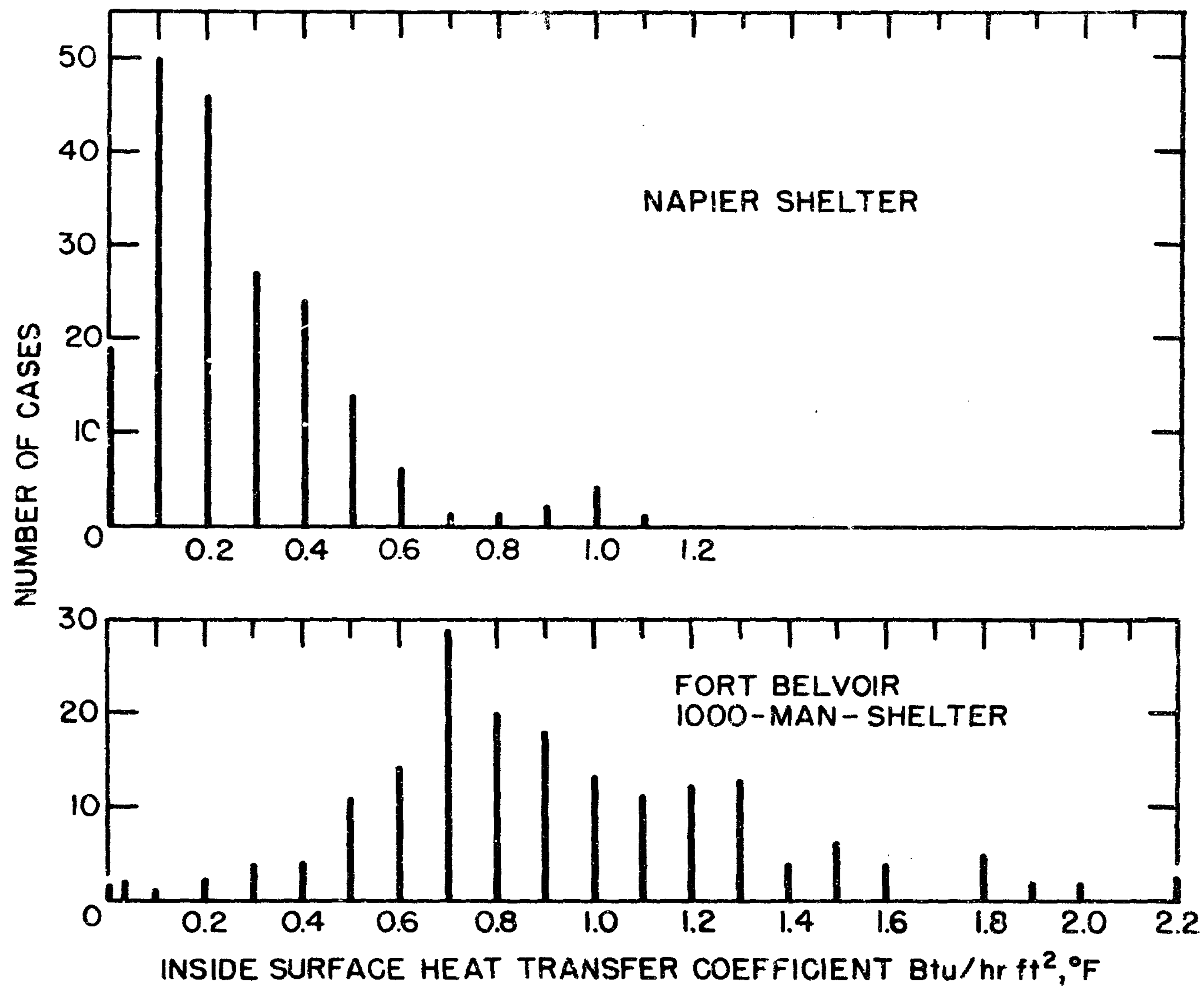

Figure 3. Inner surface heat transfer coefficient frequency distributi

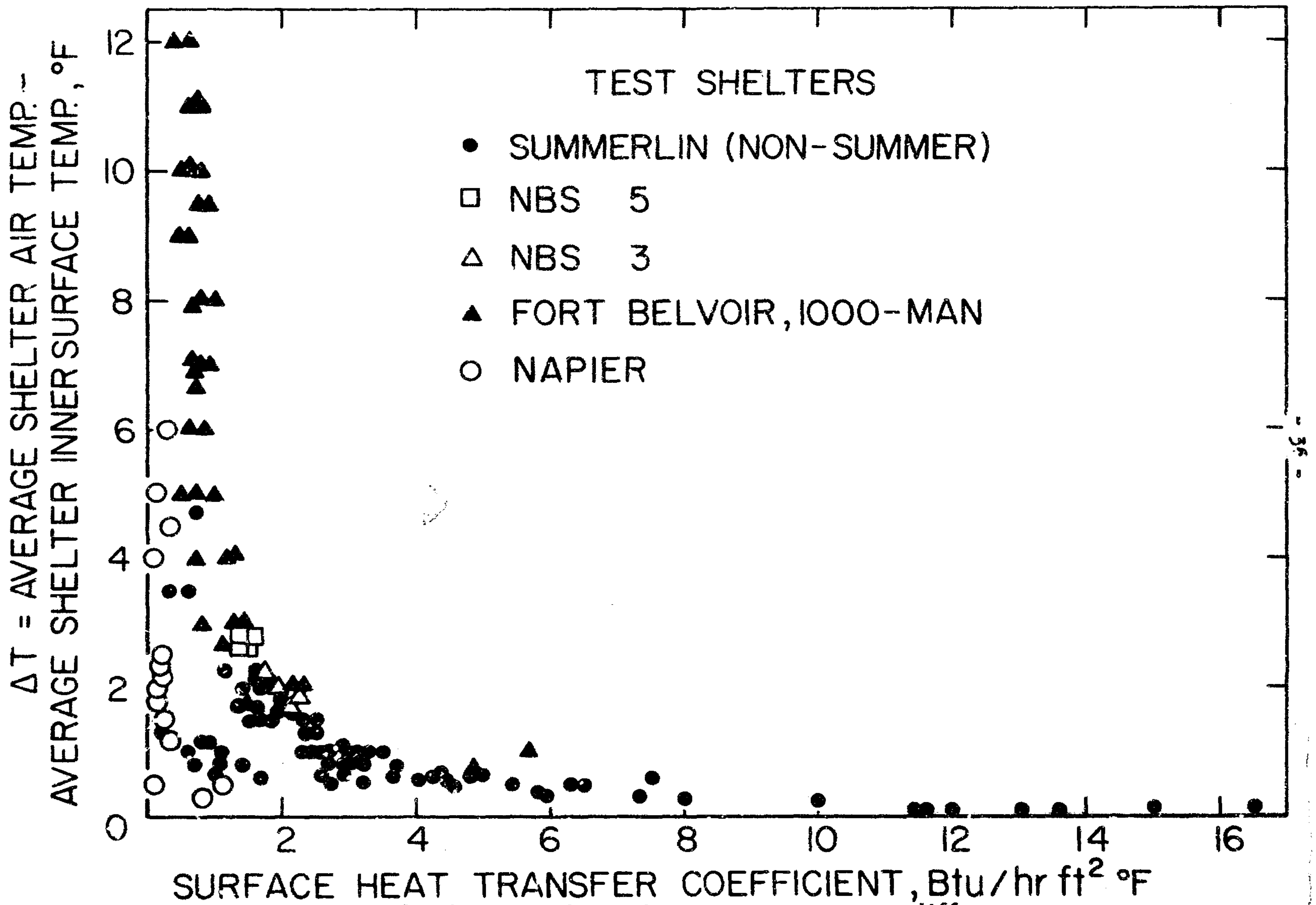

Figure 4. Inner surface heat transfer coefficient vs. temperature difference between the air and inner surface of the shelter.

surface heat transfer coefficients upon calculations of the shelter thermal environment can be seen in table 2, which illustrates a result of sensitivity analyses of inner surface heat transfer coefficients using computer program M-(2) on the NBS shelter.

In table 2, the calculated shelter surface temperatures, shelter air temperatures, and shelter air relative humidities are compared with the observed data at the end of the seventh and fourteenth day on test 5 of the NBS shelter. The symbol WG in table 2 is zero when solar heat input to the ground surface above the shelter is ignored, while it is one when the entire solar heat effect is assumed absorbed by the ground surface. If they are compared at an identical condition, the calculated shelter air temperature at the fourteenth day became approximately 3 °F higher when solar heat input was considered than when it was ignored.

For the fourteenth day results, the interior surface temperature agreement between the observed and calculated is better with rather high values of surface conductances, while better air temperature agreement is obtained with relatively low values of surface conductance. The combination of $h_W = 1.21$, $h_R = 1.43$, and $h_F = 0.57$ is obtained from reference [10] on the basis that the simulated occupants obstruct each wall from seeing each other. As far as the shelter air temperature is concerned, a combination of $h_W = 1.0$, $h_R = 1.5$, and $h_F = 0.3$ yielded the best agreement, which was also true for NBS tests 3 and 4.

5.6. Outdoor conditions.

Outdoor air conditions during the prototype shelter test periods were not the same as the ventilation air conditions, as would usually be the case for actual non-air-conditioned shelters. The ventilation air conditions were selected and programmed according to certain climactic criteria to simulate typical operating conditions of a shelter, regardless of the actual climatic condition during the test period.

The outdoor air temperatures used for the calculations in this report were recorded separately during the test, averages of which are shown in table 1.

The NBS tests included observations of solar energy at the shelter roof surface, but the tests conducted by the University of Florida did not have these data. Therefore, the inclusion of solar energy data for the shelters tested by the University of Florida was accomplished by using data supplied by Flanigan [11].

5.7. Initial earth temperature.

As described in section 3, the computer model M-(1) incorporated an earth temperature distribution normal to the surface in the six surrounding blocks. The NBS test shelter included these observations and they were used for the M-(1) calculation of this shelter. The M-(2) calculation provided for only a vertical or depthwise distribution of initial earth temperature. The observed data on roof region temperatures, average of the wall regions, and observed distribution of floor region were used to arrive at a depthwise distribution of the earth temperature. Average earth temperatures of the wall, roof, and floor regions were used for the calculations employing M-(3) and M-(4) models. Table 1 shows the overall average values of initial earth temperature which were used for the calculations in these latter two models.

5.8. Comparison between the computed and observed shelter thermal environments

Figures 5 through 25 represent some of the results obtained by computer analysis of thermal environment, together with the observed data. Figures 5, 6, 7, and 8 compare the calculated shelter thermal environments with the observed data for tests 1, 2, and 3 on the NBS

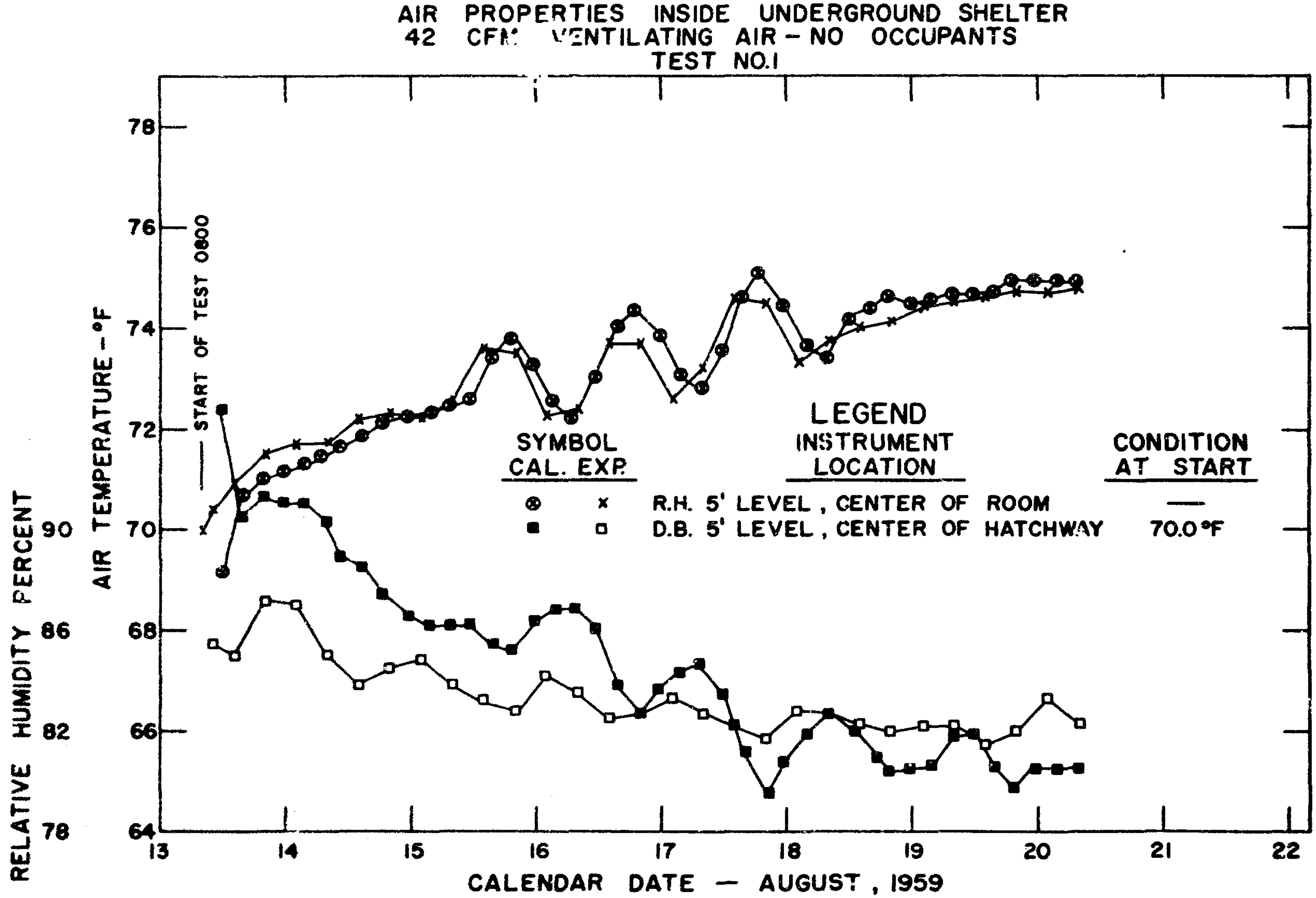

Fig. 5 Comparison of the calculated and observed shelter air temperatures and relative humidity of test 1 for NBS family shelter (computer program M-(1)).

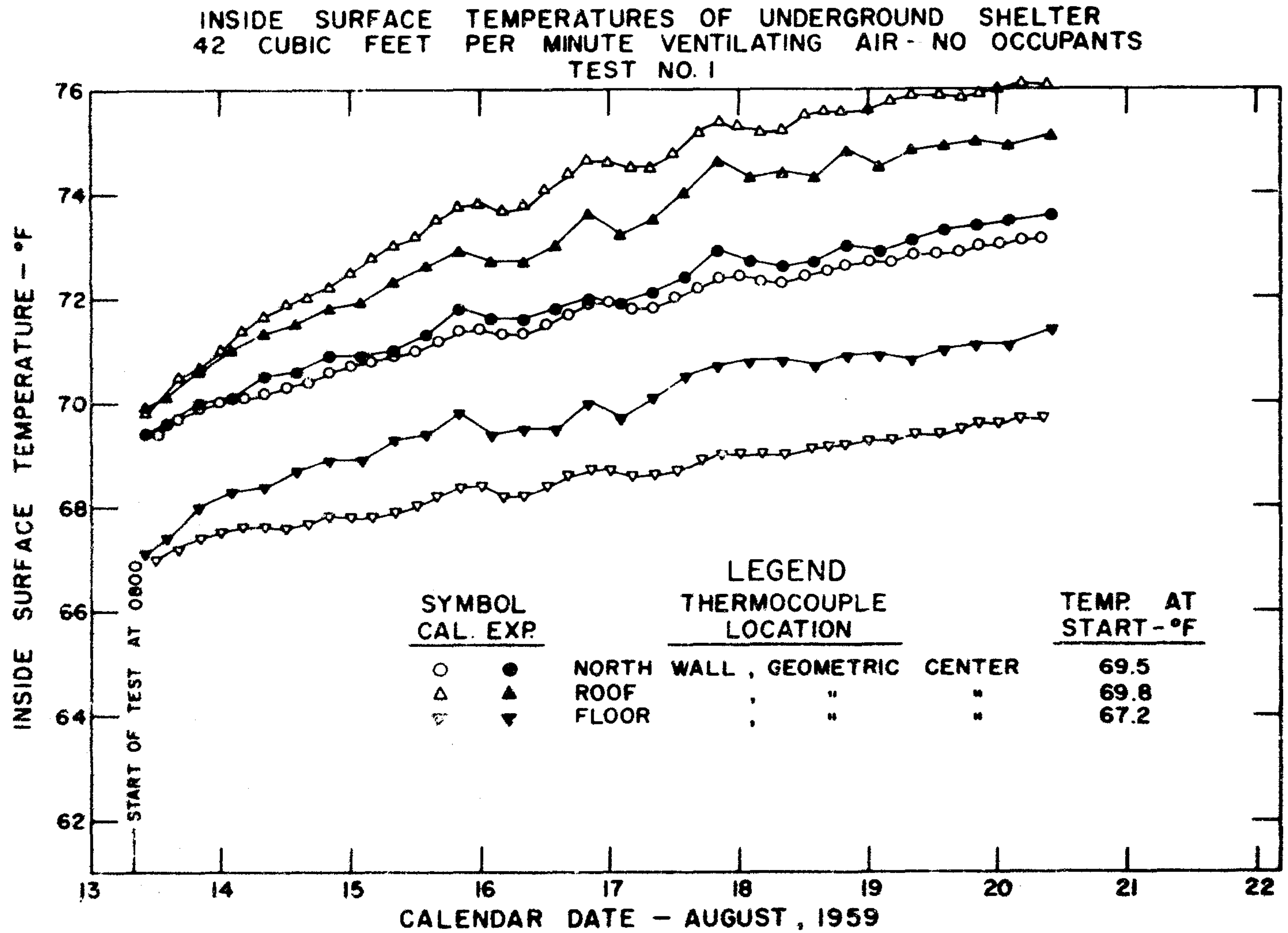

Fig. 6 Comparison of the calculated and observed shelter inner surface temperatures for test 1 of NBS family shelter (computer program M-(1)).

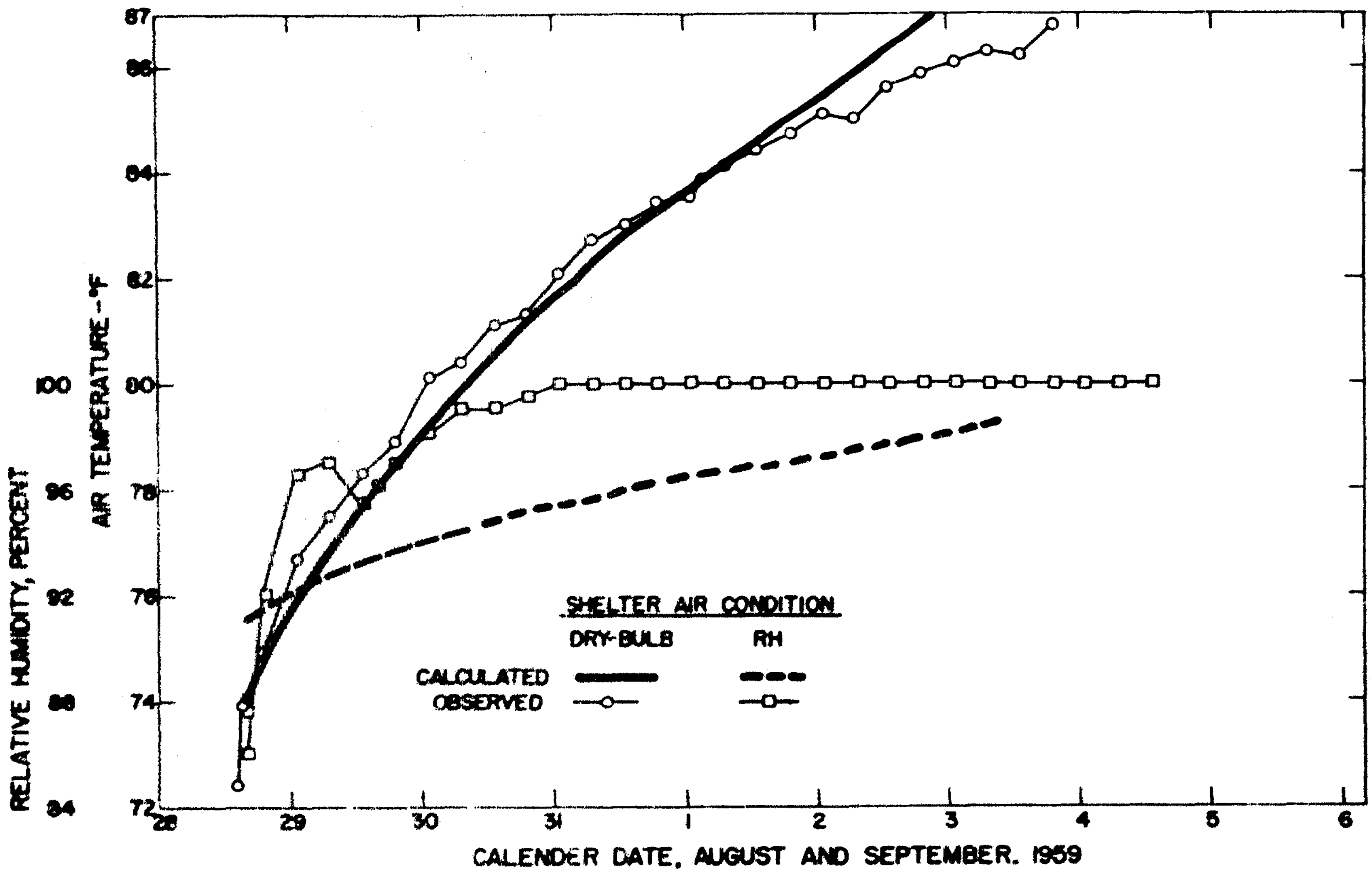

Fig. 7 Comparison of the calculated and observed shelter air temperatures and relative humidities for test 2 of NBS family shelter (computer program M-(1)).

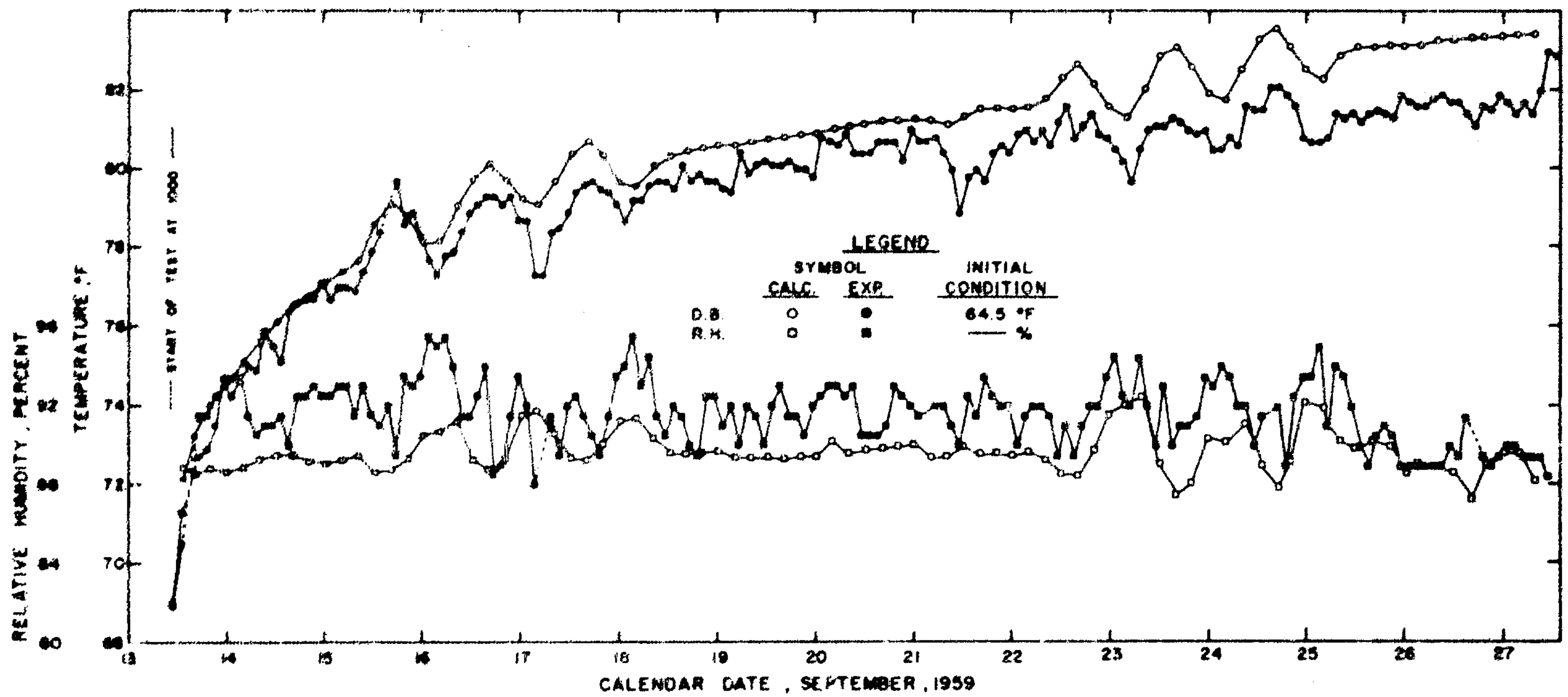

Fig. 8 Comparison of the calculated and observed shelter air temperatures and relative humidity for test 3 of NBS family shelter (computer program M-(1).

family shelter. The M-(1) computer program was used for these comparisons. Computed shelter air temperatures agreed with the observed within approximately 2 °F for the entire period of shelter occupancy. Agreement between computed and observed relative humidities was good for tests 1 and 3, and somewhat poorer for test 2 using the M-(1) program. Figure 7 represents a sealed-up condition with 6 occupants, as indicated in table 1. A very good agreement in calculated and observed air temperature for the first 4-day period is shown in figure 7. However, the calculated relative humidity was as much as 6 percent lower than the observed during the second day of test, and did not quite attain the saturated condition that was observed during the test, even after 48 hours of sealed-up condition.

Figures 9, 10, and 11 compare temperatures and humidities obtained by computer program M-(2) with the observed conditions for NBS shelter tests 3, 4, and 5. Figures 8 and 9, both for test 3 condition, show that computer program M-(1), the temperature-block model, results in better agreement with the observed shelter temperatures for the first two days than that by program M-(2), the homogeneous-earth model. This was expected, because program M-(1), as explained before, is considerably more elaborate in accounting for a complex nature of initial earth temperature distribution around the shelter than program M-(2), and also takes into account the differences in thermal properties of the concrete and the earth.

A. However, the agreement between the calculated and observed air temperature at the 5-foot level in the shelter was somewhat better using the M-(2) program than the M-(1) program during the last 4 or 5 days of test 3.

The agreement of the computed shelter air temperature with the observed condition for test 4 of the NBS shelter became poorer toward the end of the test. The lowering of the computed shelter temperature during the second week of the test was caused primarily by a decrease in outdoor temperature. This temperature decrease averaged approximately 15 degrees, beginning on October 12 and continuing to the end of the test period. The detailed report [3] on these tests indicates a steady and significant decline of earth temperature during this period. The curves on figure 10 shows that the observed shelter air temperature was not affected as significantly by this cool spell as the computer model indicated that it would be.

The sudden and irregular drop of the calculated relative humidity for the NBS test 5 condition shown in figure 11 is not reflected by the observed data. It is probable that the relative humidity in the shelter was sustained at a high level by drying of the shelter walls. The moisture balance between the supply and exhaust air indicated that this evaporation amounted to approximately 2 to 2.5 lb/day during this winter test condition where extremely dry ventilation air was employed. As indicated earlier, the computer program developed for this analysis had no provision for taking this drying process into consideration. Table 2 indicates that the calculated air temperature at the end of 14 days in the NBS test shelter test 5 condition is in better agreement with the observed value when solar heat effect was not included for the ground surface heat exchange than when it was included. The ground surface was quite wet during this test period because of a snow prior to the test. This implies that during this particular test period the solar heat was mostly absorbed by evaporation of water on or near the earth's surface

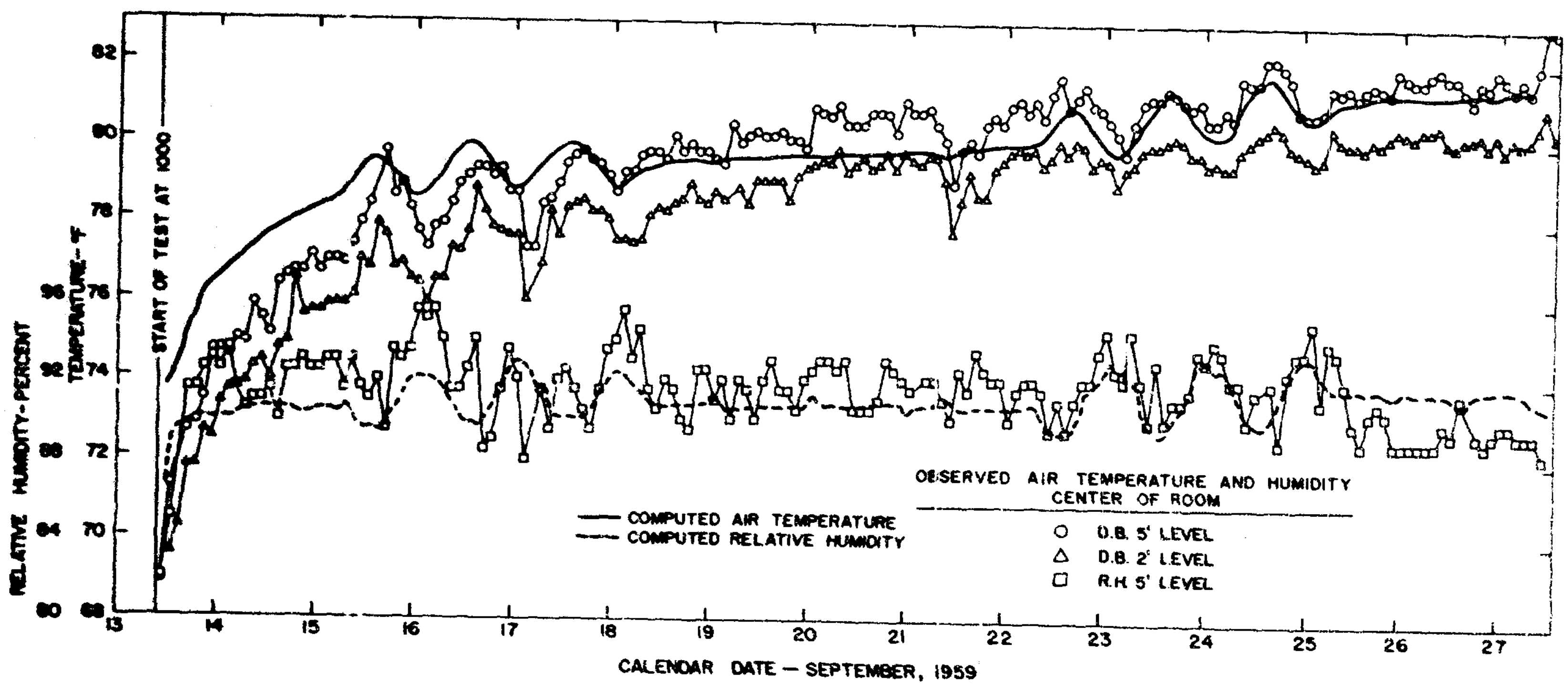

Fig. 9 Same as Fig. 8 but using computer program M-(2).

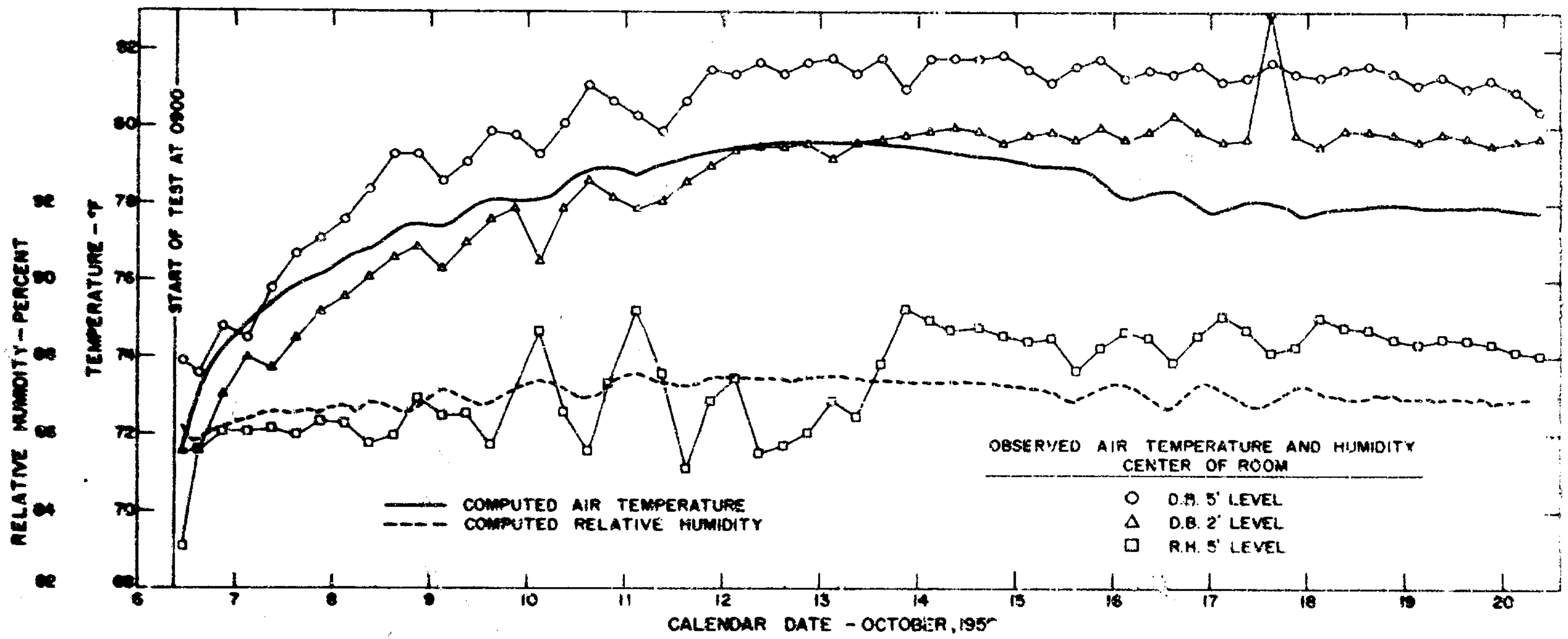

Fig. 10 Comparison of the calculated and observed air temperatures and relative humidities for test 4 of NBS family shelter (computer program M-(2)).

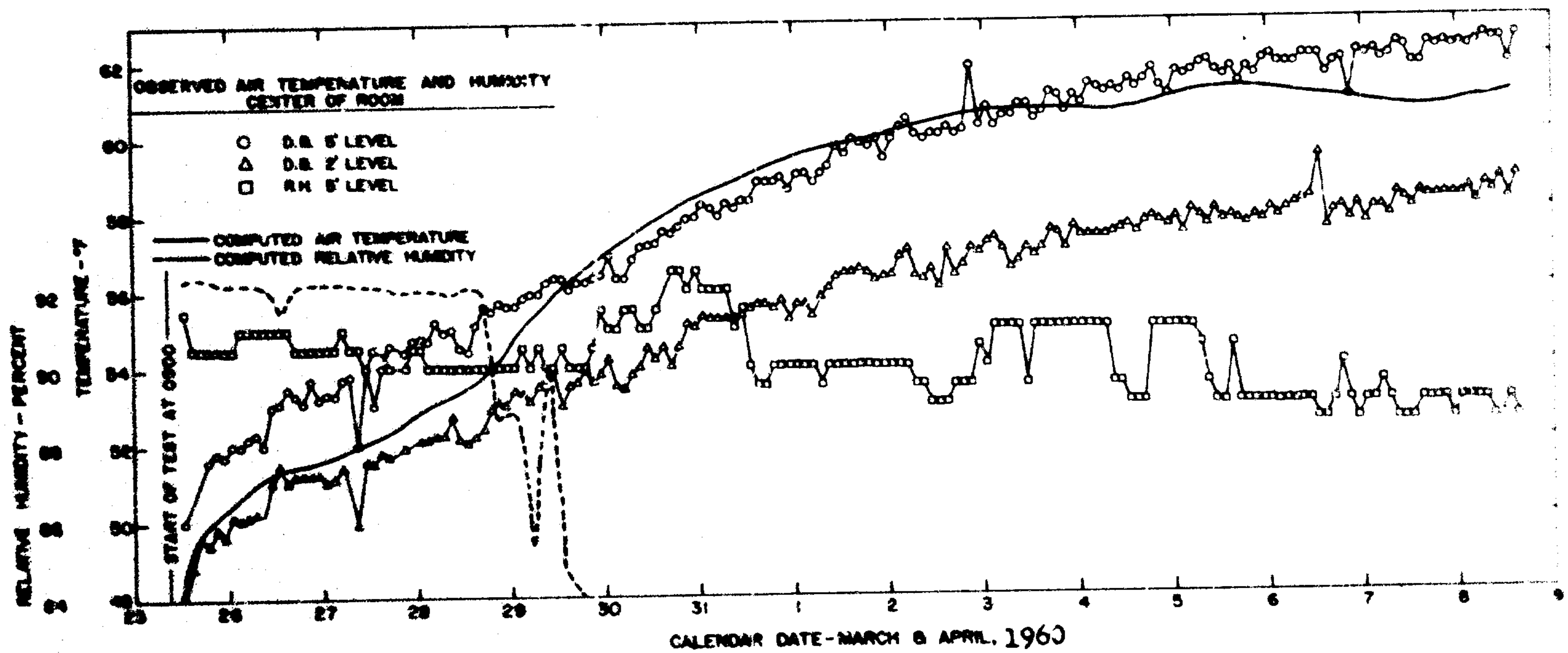

Fig. 11 Comparison of the calculated and observed shelter air temperatures and relative humidities for test 5 of NBS family shelter (computer program M-(2)).

and did not cause appreciable temperature rise in the ground. Similar moisture evaporation near the earth's surface also explains the small earth temperature rise near the surface for other test conditions, such as the Summerlin, Broyles, and Napier shelters, some of which will be illustrated later.

Figure 12 compares calculated (M-(2) program) and observed air temperatures in the Summerlin shelter for its summer condition test. Although the overall trend of the actual temperature is closely followed by the calculation, the computed amplitude of the diurnal temperature variation within the shelter is considerably smaller than the observed. The relative humidity calculation for the summer test condition of the Summerlin shelter is shown in figure 13. For the first five days, the calculated relative humidity was higher than the observed. This discrepancy may be due to the fact that there were cool regions in the shelter interior surfaces where more condensation of water vapor was taking place than was determined by the calculation which was based upon average surface temperatures of each exposure. Some of the high peaks in the computed relative humidity during the last three days were not registered in the observed record. Figure 14 compares the calculated earth temperature surrounding the Summerlin shelter during the summer test period with the observed. The agreement between calculated and observed values was quite good for the south and east walls. The earth temperature under the floor was not observed during the test because this was a privately owned shelter and it was decided that the water-tightness of the floor should not be jeopardized by making a hole through it. The calculated roof region temperature was much higher than the observed values. As mentioned before, this discrepancy is assumed to be caused by partial utilization of solar energy by surface evaporation of ground moisture,

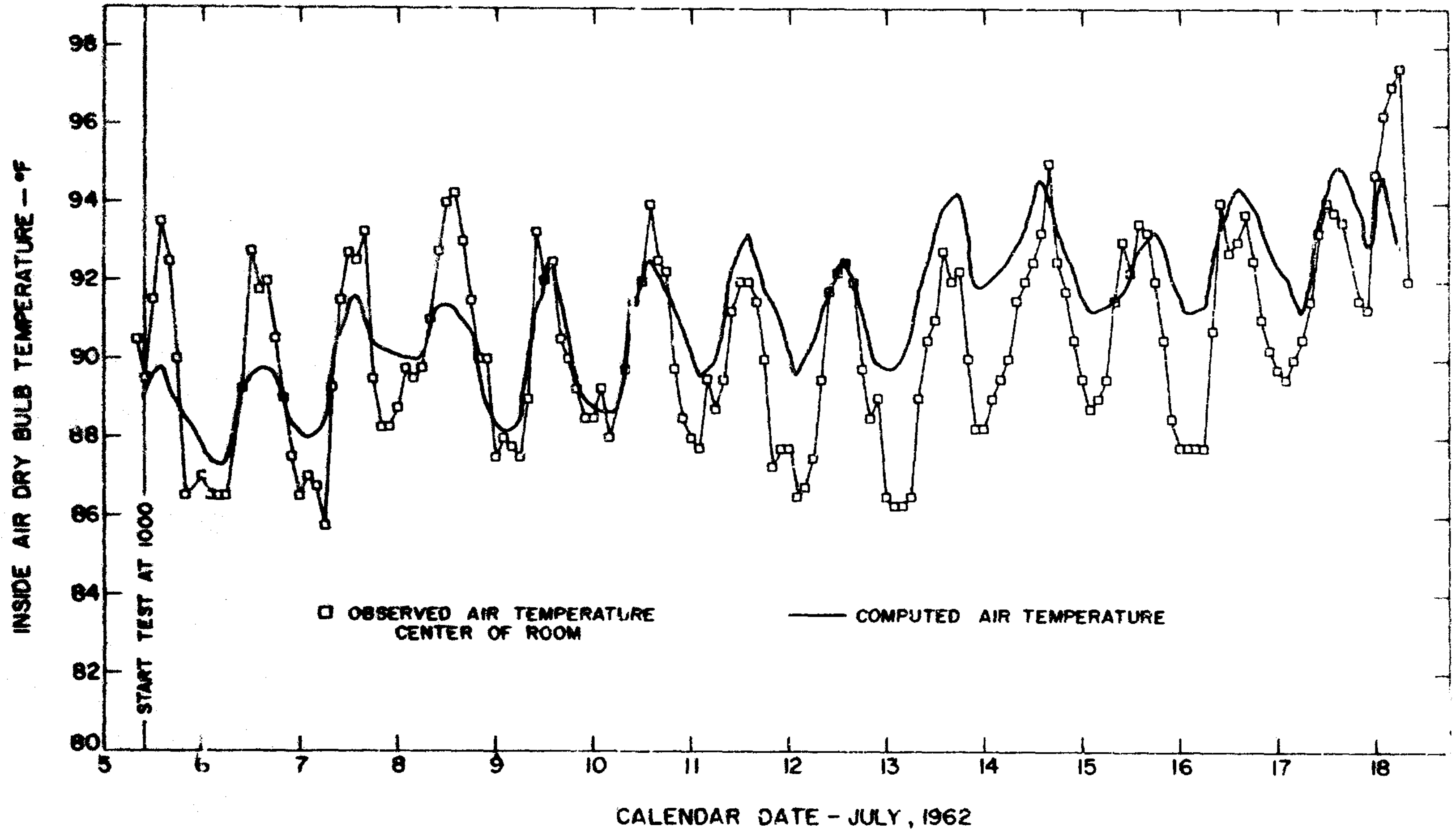

Fig. 12 Comparison of the calculated and observed shelter air temperatures for Summer Condition test for Summerlin Shelter (computer program M-(2)).

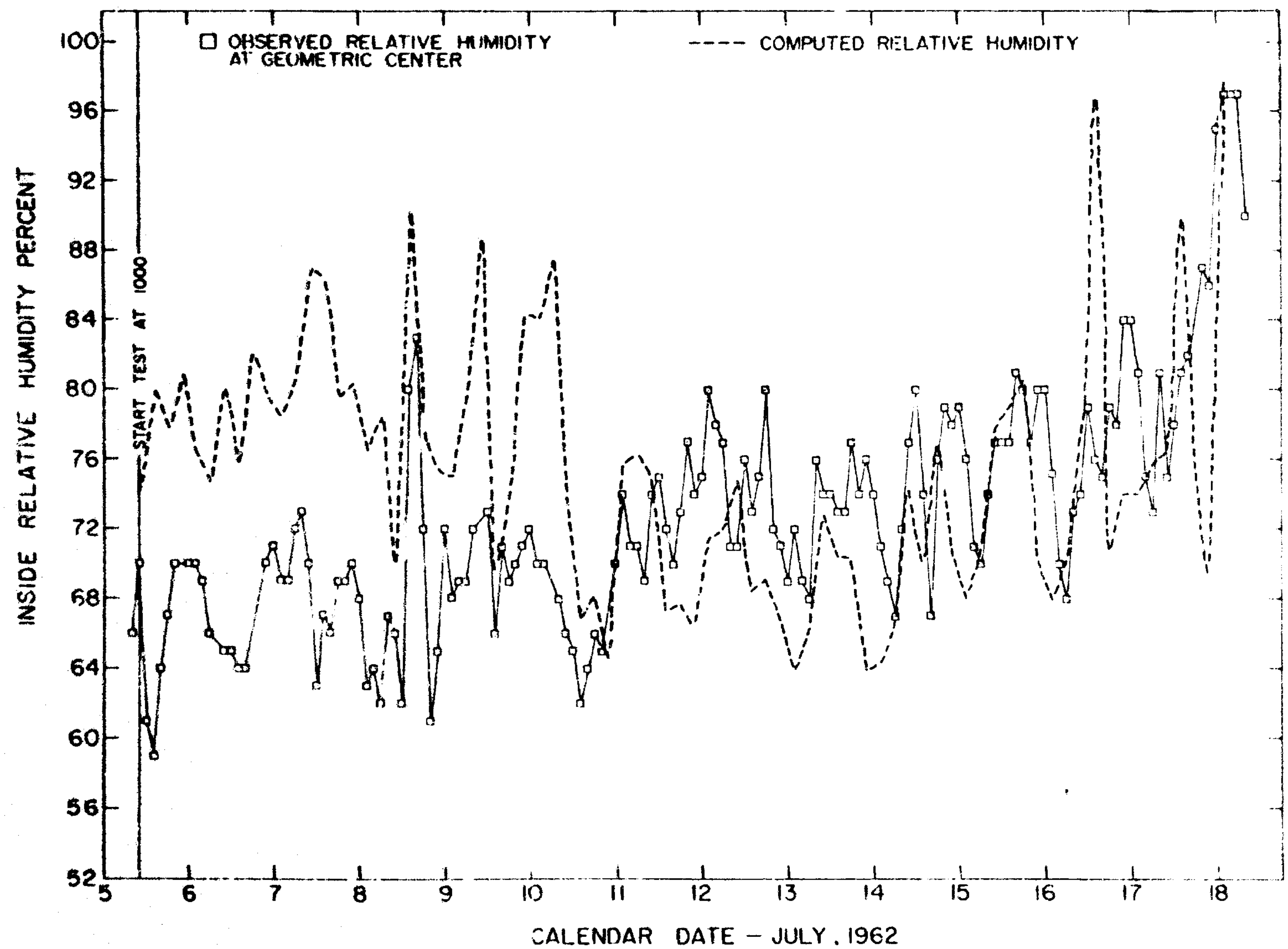

Fig. 13. Comparison of the calculated and observed shelter air relative humidities for summer condition test for Summerlin Shelter (computer program M-(2)).

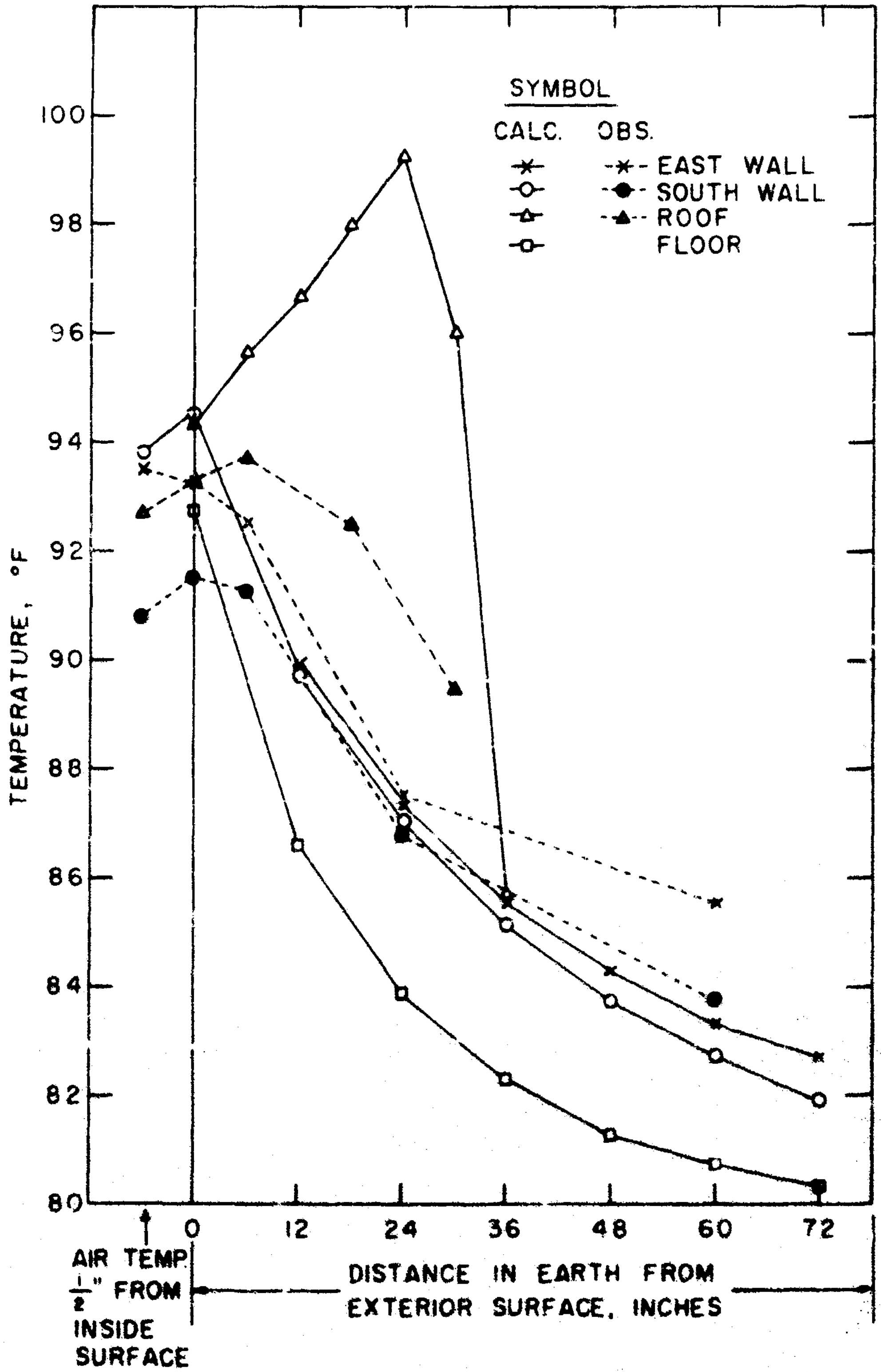

Fig. 14. Comparison of the calculated and observed earth temperatures surrounding Summerlin Shelter during summer test conditions (computer program M-(2)).

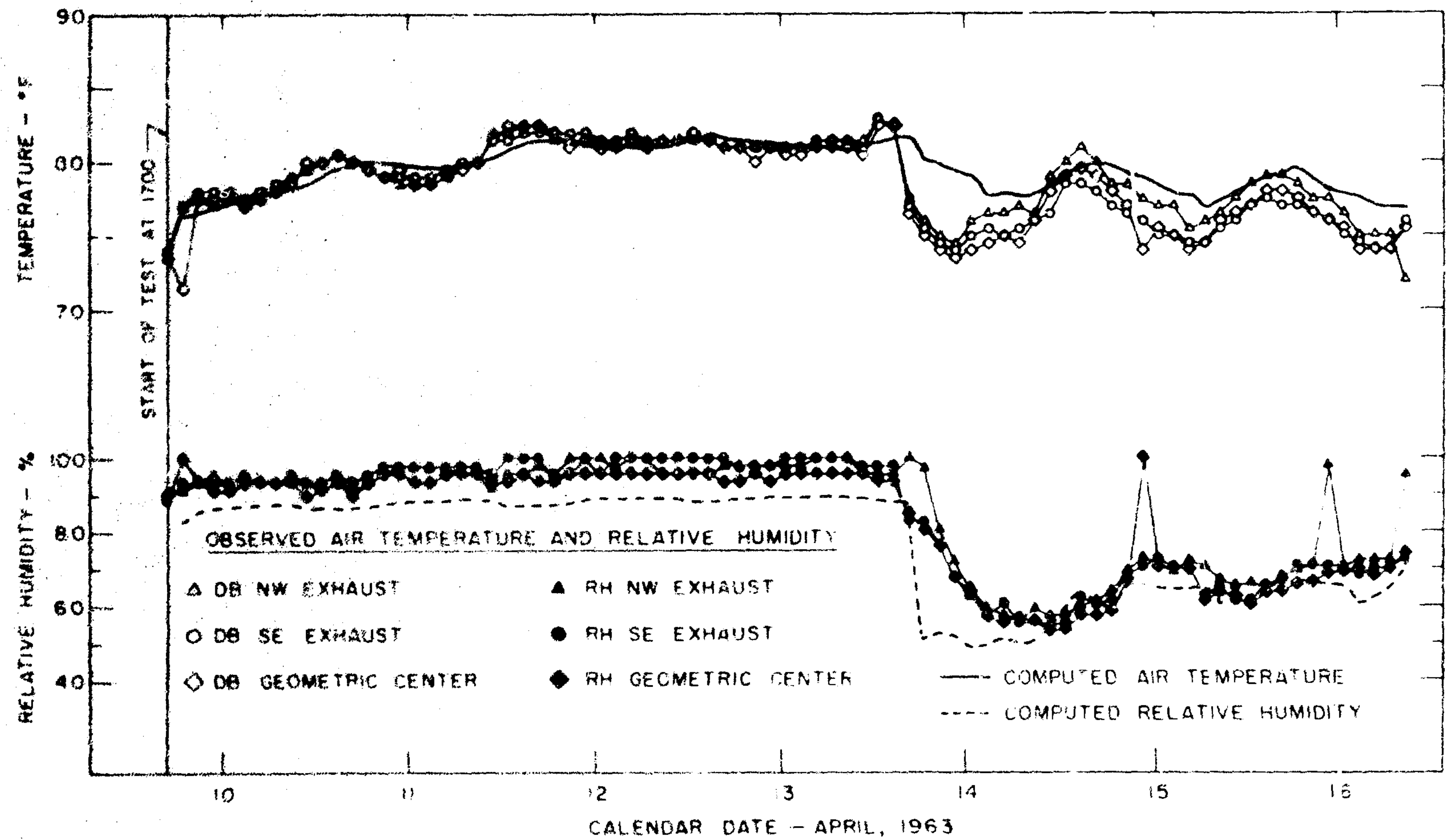

Fig. 15. Comparison of the calculated and observed shelter air temperatures and relative humidities during winter condition test for Summerlin Shelter (computer program M-(2)).

resulting in less temperature rise in the interior of the earth than calculated. It was found for all other shelters for which the ground surface was not dry and bare, the inclusion of solar heat in the calculation usually gave higher shelter temperatures, as well as higher roof region temperatures, than observed values.

Figure 15 compares the computed Summerlin shelter thermal environment with the observed condition for a moderate climatic condition. Although the computed temperature amplitude was again lower than the observed, the agreement between the computed and the observed data is very good and was better than for the hot summer test condition. Three high peaks of the observed shelter relative humidity during the last two days of the test were not reproduced by the calculation and they may represent instrumentation errors. Essentially identical results were obtained when the calculations were repeated by M-(3) or one-dimensional compound model on Summerlin shelter.

Figures 16 and 17 compare calculated results with observed temperature and relative humidities of the Broyles shelter. As described in section 4-C, this shelter was conditioned by a cooling coil using well water during the first two days. In figure 16, a dashed curve shows the computed result without consideration of the cooling coil, thus yielding much higher shelter temperatures during the first two days of the test. The last 2-day portion of figure 16 was not simulated by the computer, so the comparison between the calculated and the observed shelter temperature without air conditioning should be made between August 1 and 16. However, an adjustment was made later to account for the observed cooling capacity of the coil by making Q_{MS} and Q_{ML} negative in the equation for miscellaneous heat load in section 2. The first 2-day portion of the Broyles shelter calculation was repeated with this adjustment and the

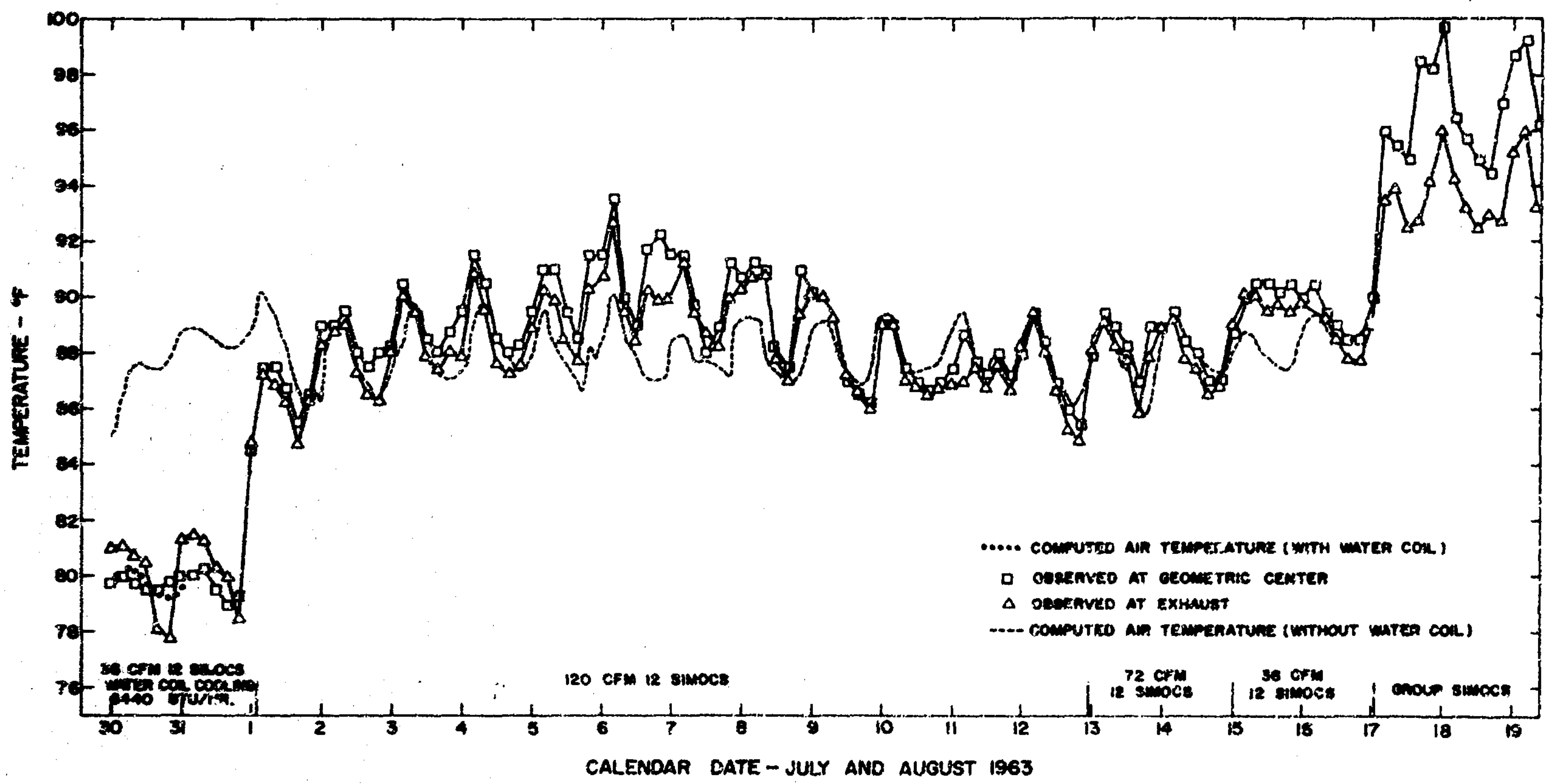

Fig. 16. Comparison of the calculated and observed shelter air temperatures for Broyles Shelter (computer program M-(2)).

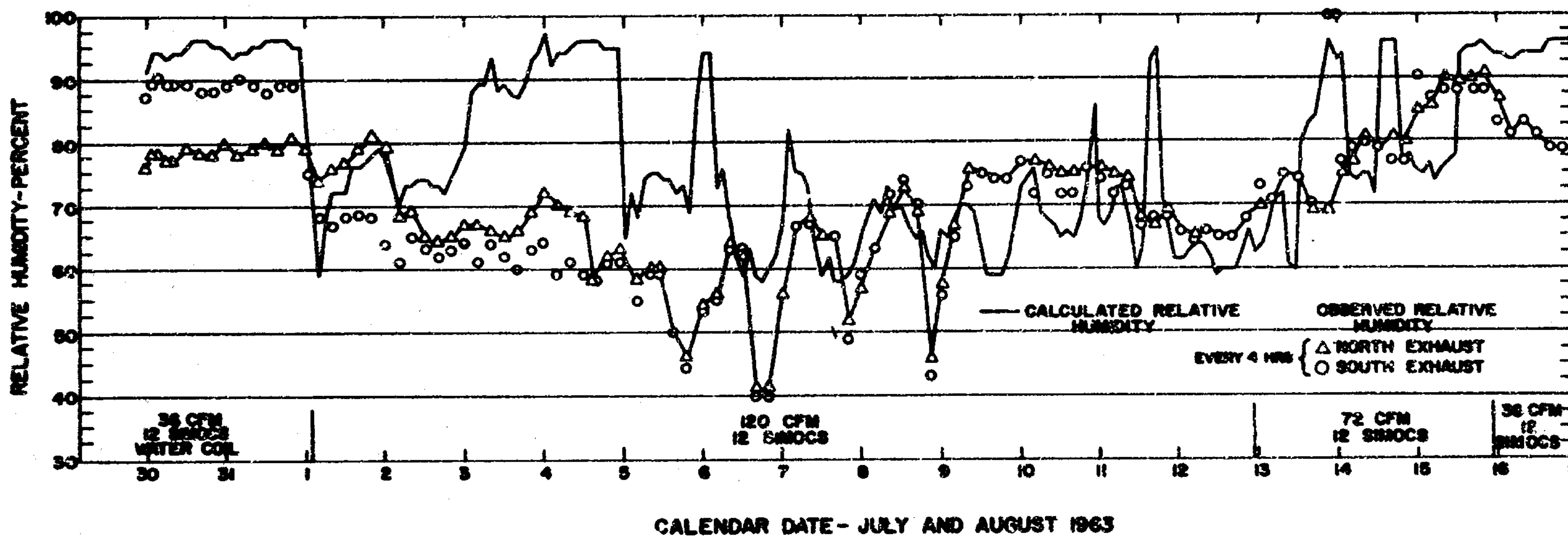

Fig. 17 Comparison of the calculated and observed shelter relative humidities fo r Broyles Shelter (computer program M-(2)).

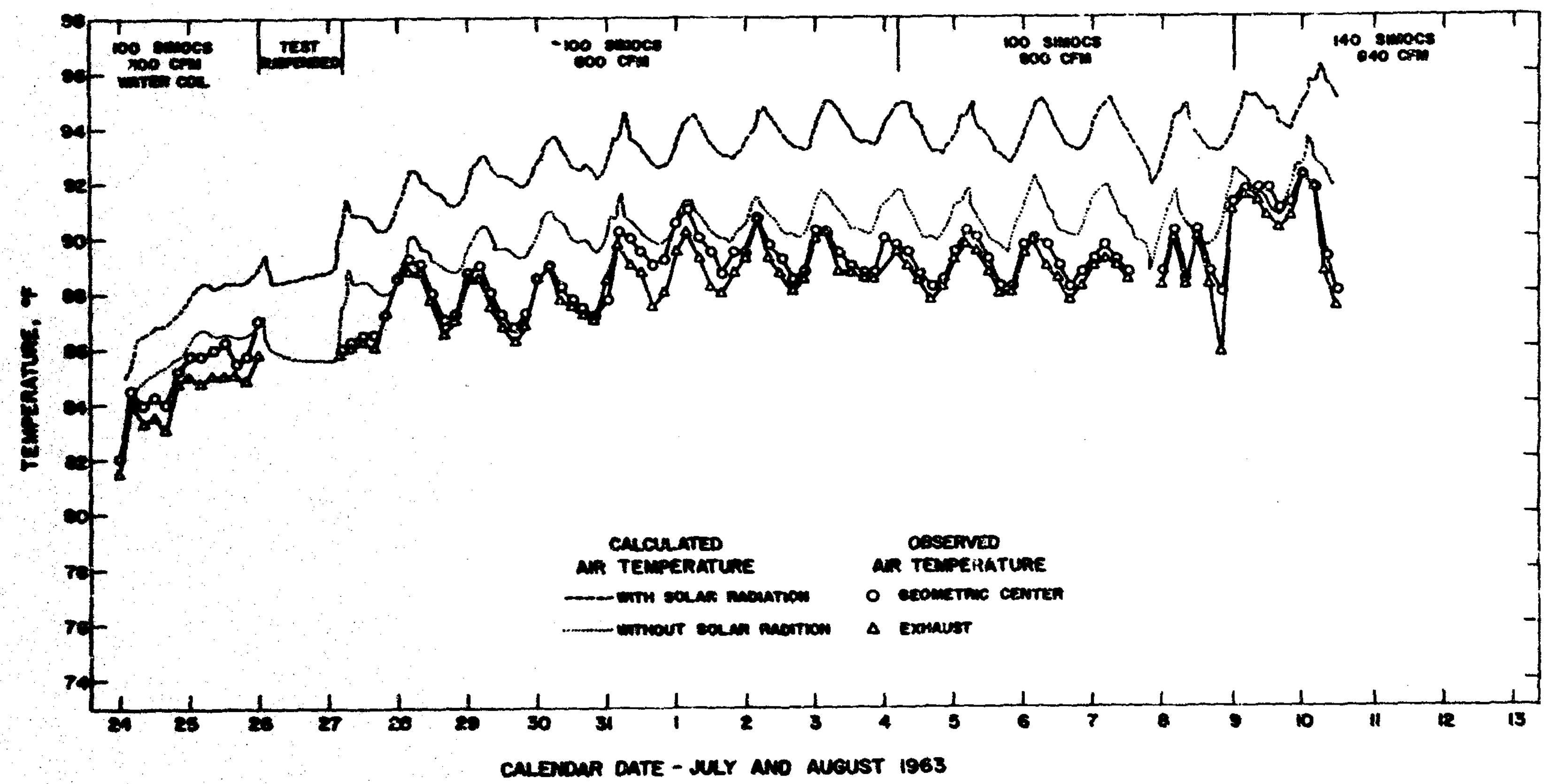

Fig. 18. Comparison of the calculated and observed shelter air temperatures for Napier Shelter (computer program M-(2)).

results are shown by solid dots on figure 16. The adjusted and calculated shelter air temperatures for this initial 2-day period agree very well with observed temperatures obtained at the geometric center of the shelter

Figure 17 compares the calculated and observed relative humidities in the Broyles shelter. The large disagreement of the computed relative humidities during August 2 to 7 cannot be explained adequately by the available data. The agreement of the computed relative humidities with the observed values for this test were generally very poor, and the same trend was also observed in the Napier shelter comparison, as shown in figure 19.

The Napier shelter temperature comparison was satisfactory if the solar heat input to the ground surface is ignored, as seen from figure 18. The inclusion of the solar heat in the calculation caused the computed shelter air temperature to be approximately 3 to 4 degrees higher than the observed temperature.

By contrast, figure 20 shows excellent agreement between the calculated and observed temperature and relative humidity during the winter test condition for the Reading shelter. For this shelter, nearly 80 percent of the total heat generated was conducted into the surrounding earth. The moisture balance of the test results is shown in figure 21, indicating the continuous condensation of water vapor on the inner surfaces of the shelter during the first ten days of the test. The ventilation rate was either 3 cfm or 1½ cfm per person during this period. The excellent agreement between the computed thermal environment with the observed condition during the first 10-day period is a good demonstration that the computer simulation technique was valid. However, in

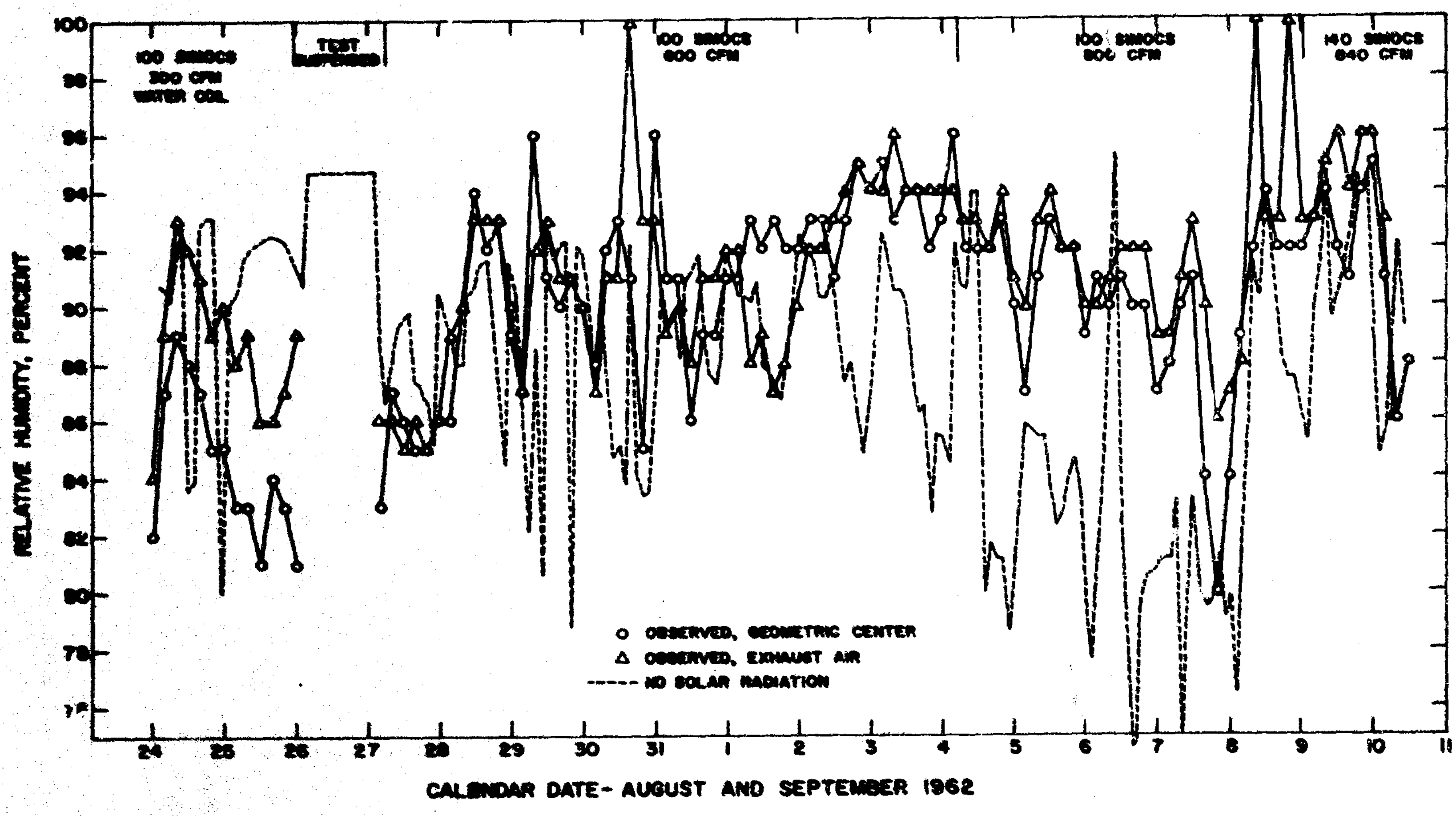

Fig. 19 Comparison of the calculated and observed shelter relative humidities for Napier Shelter (computer program M-(2)).

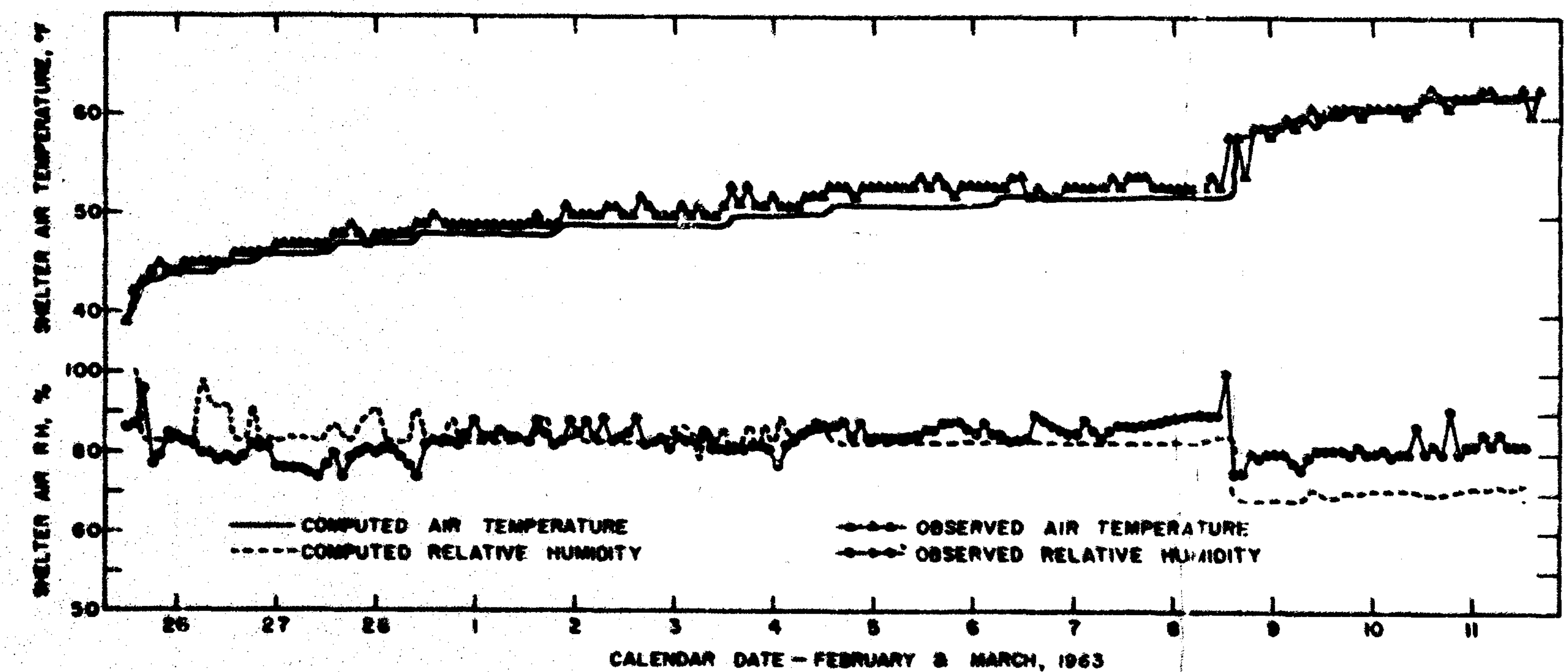

Fig. 20 Comparison of the calculated and observed shelter air temperatures and relative humidities for Reading Shelter (computer program M-(2)).

figure 20, the computed relative humidity is approximately 10 percent lower than the observed during the last three days. During this period, the simulated occupants were increased from the equivalent of 50 to 100. In figure 21, the indicated moisture balance within the Reading shelter during this period shows that the ventilation air actually carried out more water vapor than was produced by all of the simulated occupants. This proves that the shelter wall was drying out during the period. As mentioned before, the computer program does not have provision for simulating the drying process of concrete walls; therefore, the computed relative humidity was lower than the observed.

Figures 22 and 23 compare the computed and observed earth temperatures surrounding the Reading shelter. Being in the midst of winter, the undisturbed earth temperature was relatively low and the ground surface was snow covered during this period. Two computer models M-(2) (symmetrical and three-dimensional) and M-(3) (one-dimensional and compound), were applied to the Reading shelter calculation, resulting in practically identical thermal environments. The ground temperature profiles were computed and compared with the observed profiles for other prototype shelters and the agreement between the calculated and observed results were generally similar to those shown in figures 22 and 23 for the Reading shelter.

The computer Model M-(4), basically a one-dimensional and compound system with the top surface of the roof being adiabatic, was employed to compute the thermal environments of the Ft. Belvior 200-man and 1000-man basement-type shelters. These results are shown graphically in Figures 24 and 25. Instead of comparing the relative humidity, as in cases of other shelters, effective temperatures were compared, in addition to the dry-bulb temperature comparison. The computed and observed results agreed almost

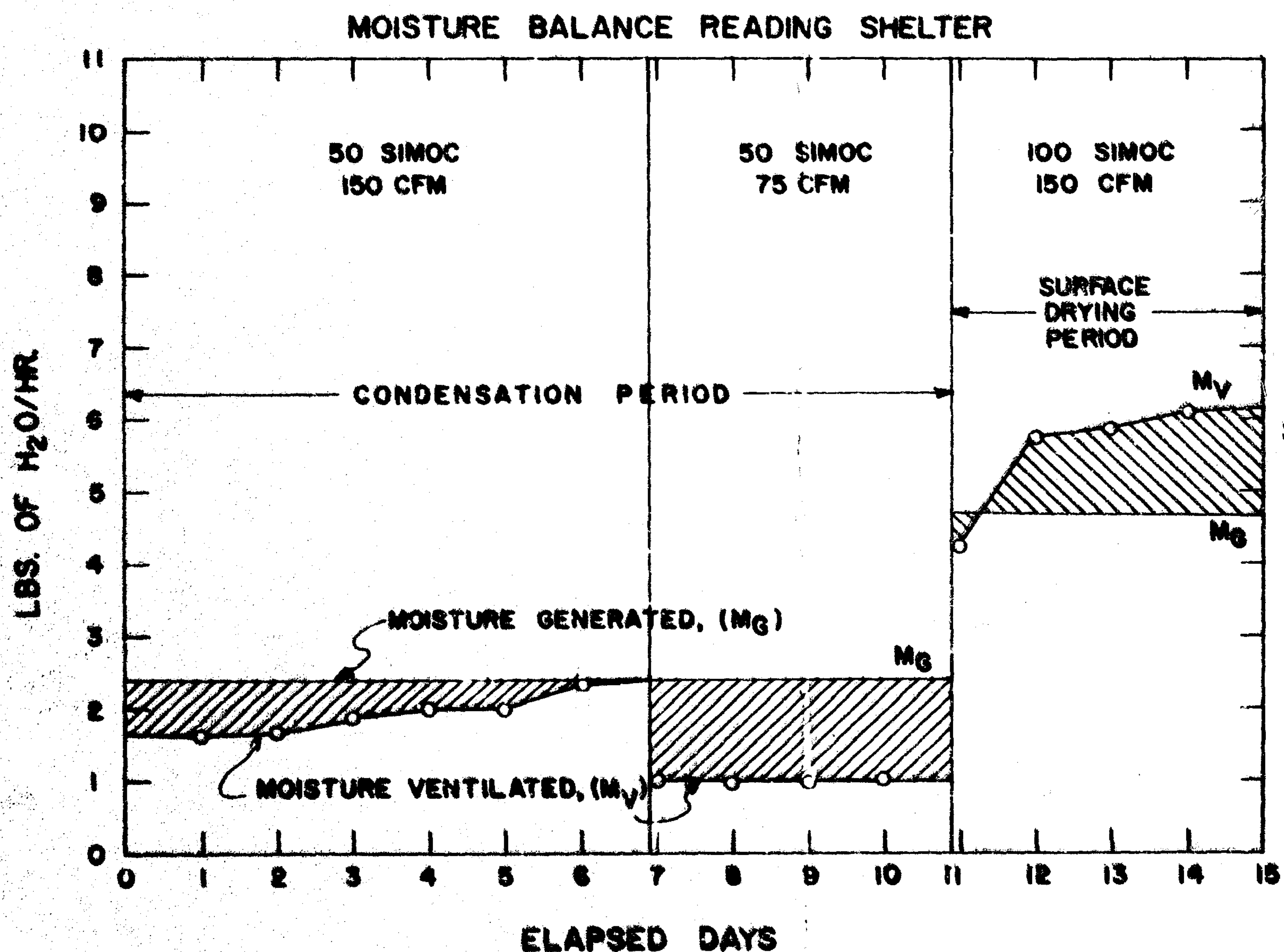

Fig. 21 Observed moisture balance of Reading Shelter.

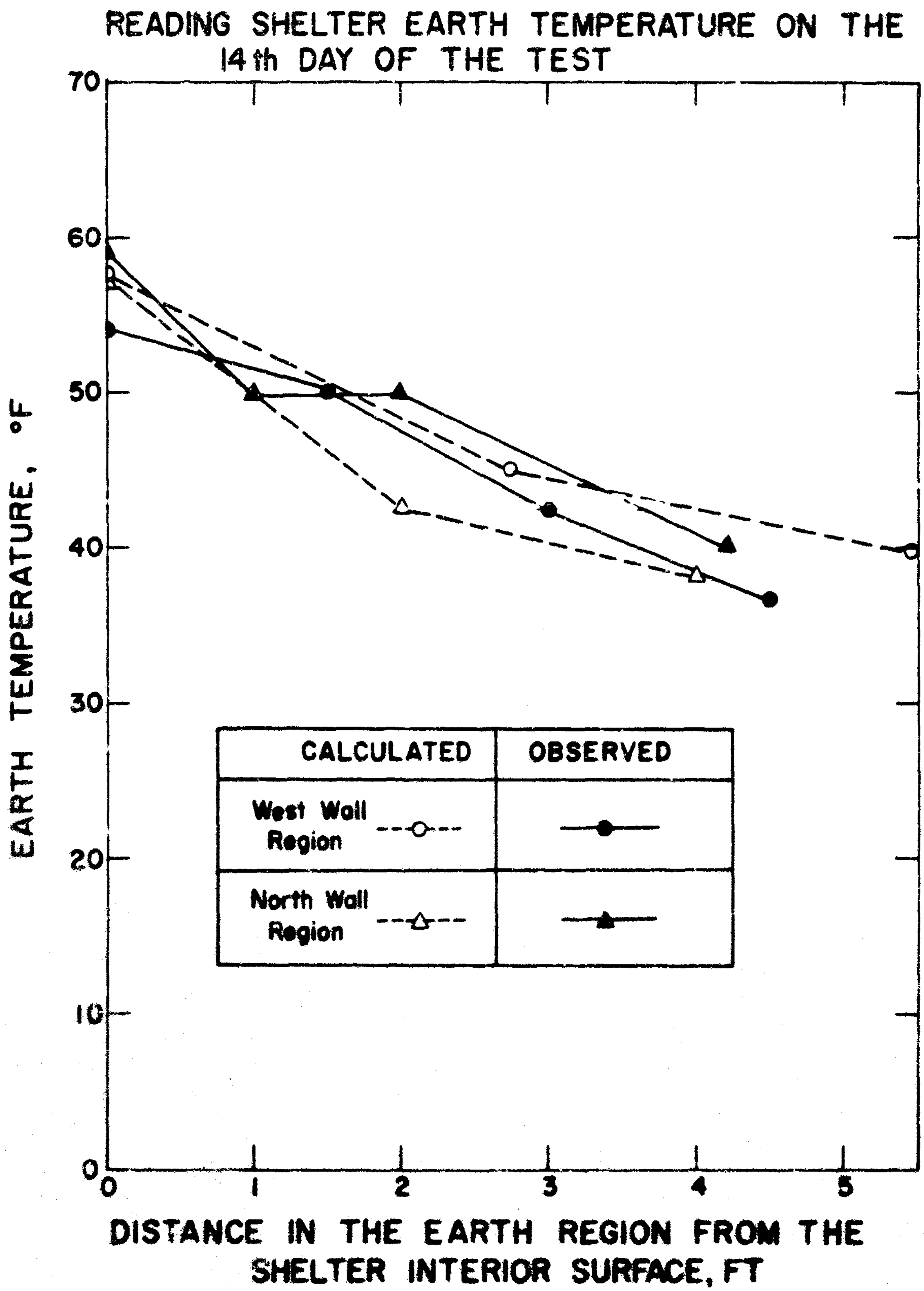

Fig. 22 Comparison of the calculated and observed earth temperatures outside Reading Shelter walls (computer program M-(2)).

READING SHELTER EARTH TEMPERATURE ON THE 14 th DAY OF THE TEST

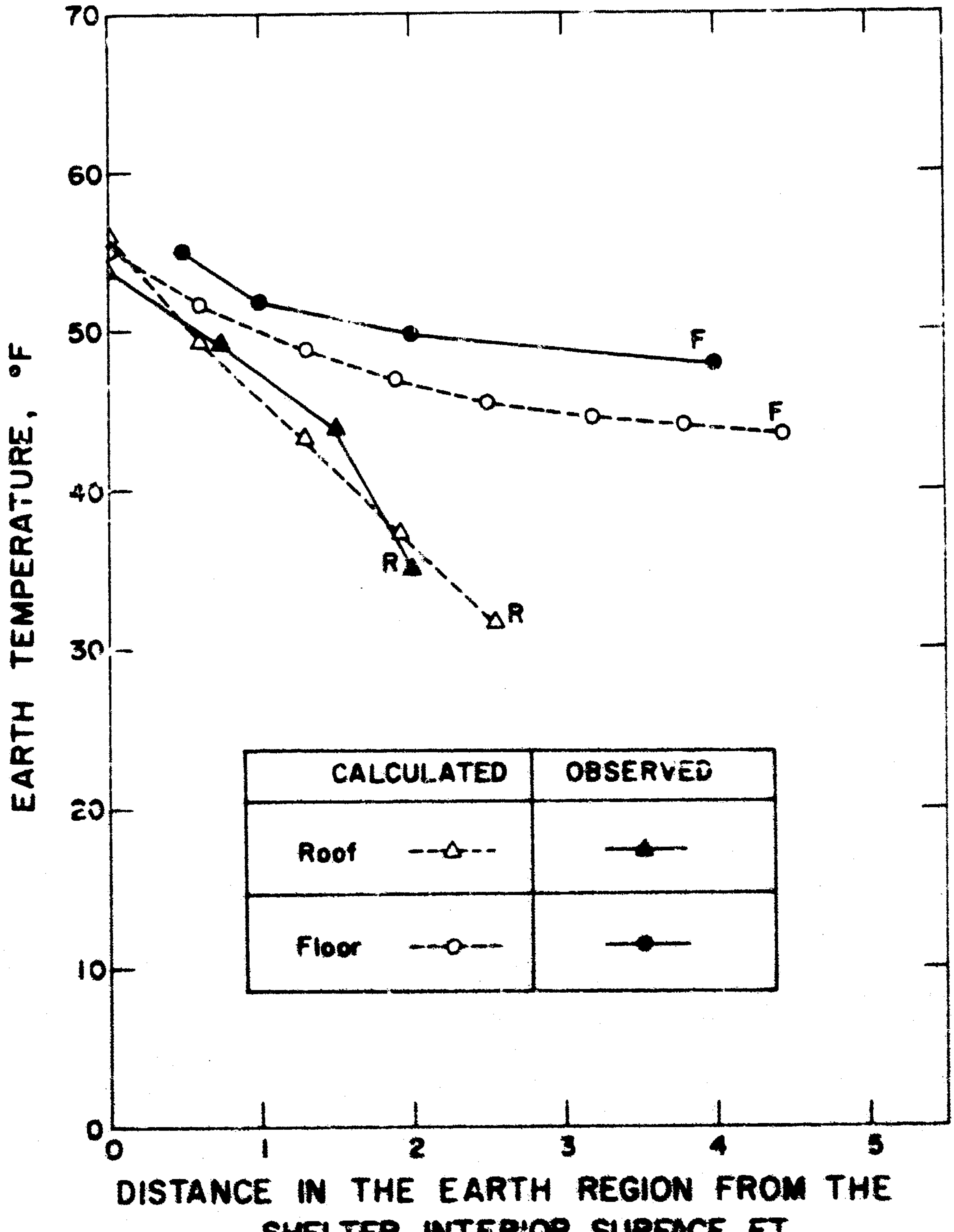

Fig. 23 Comparison of the calculated and observed earth temperature outside Reading Shelter ceiling and floor (computer program M-(2)).

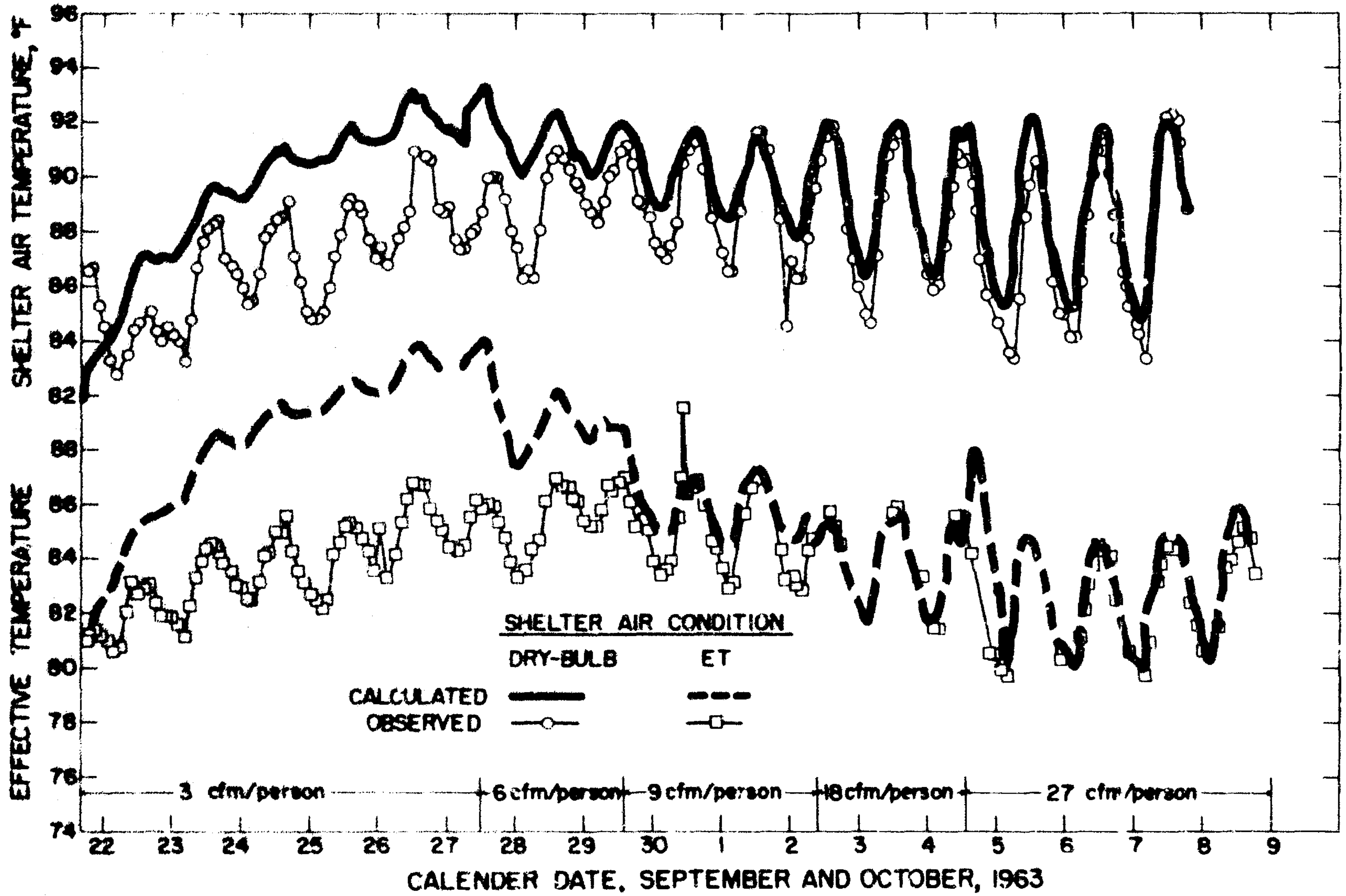

Fig. 24 Comparison of the calculated and observed shelter air temperatures and effective temperatures of Ft. Belvoir 200-man shelter.(computer program M-(4)).

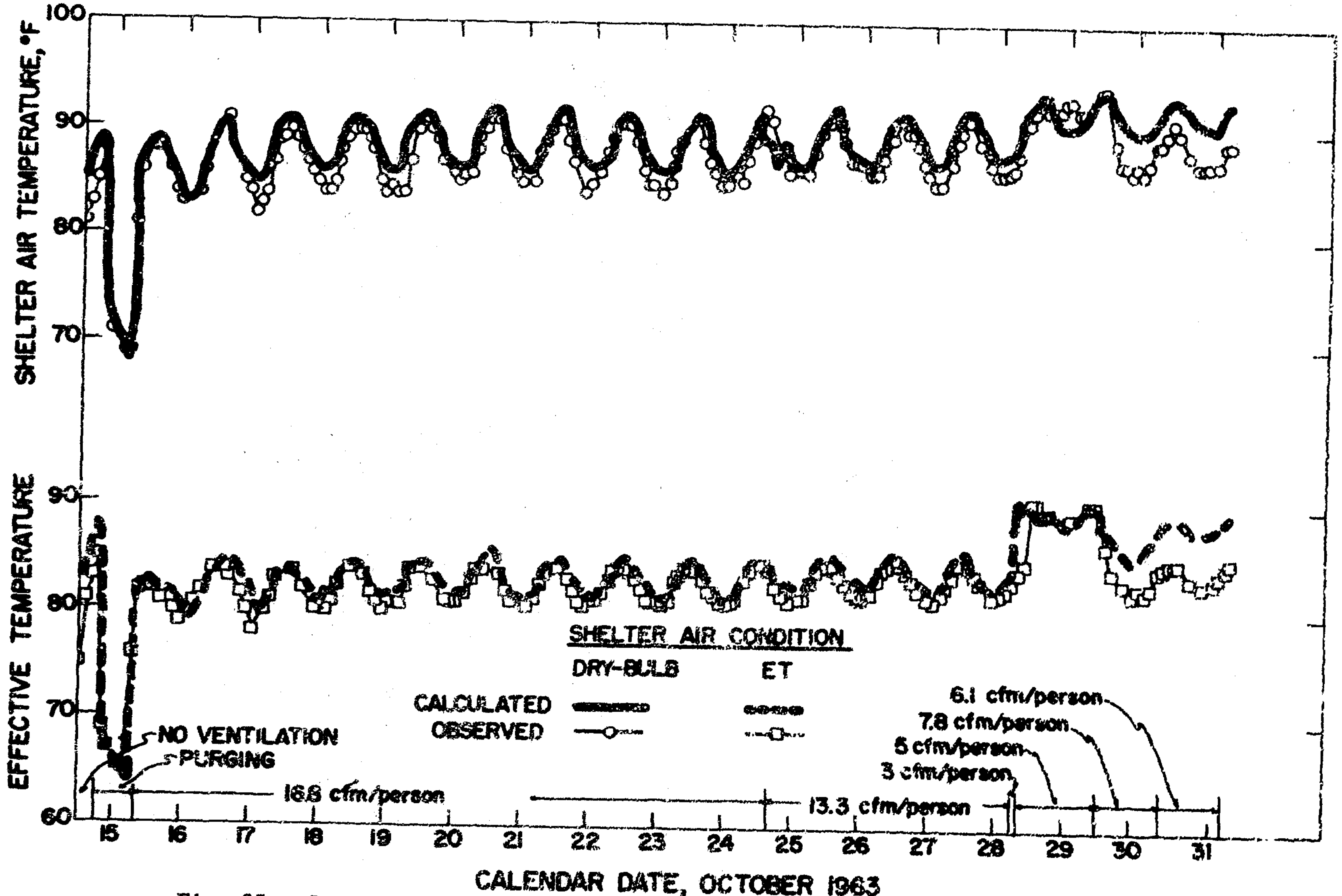

Fig. 25 Comparison of the calculated and observed shelter air temperatures and effective temperatures of Ft. Belvoir 1000-man shelter (computer program M-(4)).

perfectly for the 1000-man shelter. Higher and less fluctuating dry-bulb and effective temperatures were calculated for the 200-man shelter than were observed, particularly during the first seven days of the test period. By comparison it appeared that the observed temperatures reflected shelter diurnal cycles corresponding to a higher ventilation air rate than the indicated 3 cfm per person. It also should be realized that the geometrical relationship between the inlet for the ventilation air and the stations for room temperature measurement and the mixing effects in the intervening space would have an effect in the amplitude of the temperature variations observed in any of the shelters.

6. CONCLUSIONS

Except for a very few cases, such as for the Napier shelter and the NBS shelter test 4 conditions, the computer simulation based upon a finite difference solution of the heat conduction equation for the calculation of the thermal environment of underground protective shelters has been found generally satisfactory. Good agreement between calculated and observed thermal conditions was obtained for tests 2 and 3 in the NBS shelter, the Summerlin shelter, the Reading shelter, and the Ft. Belvoir 1000-man shelter. This agreement coincided with well-controlled test conditions, and where input parameters were known more accurately than in other cases. However, for this type of analysis there are two inherent uncertainties which influence the accuracy of the calculations.

The first uncertainty stems from simplification of the actual environmental system when constructing the mathematical model. The

complexity of the system including construction details of interior partitions, foundations, wall supports and reinforcing; the heterogeneous temperatures, thermal properties, and types of the surrounding earth; and space variation of conditioning air and its convective pattern in the shelter, makes an accurate mathematical description of the system very difficult. Therefore, the simulated computer model is a simplified version of the actual system that is suited to the mathematical handling of the problem. The magnitude of the error due to this uncertainty has not been evaluated, but it is a part of the differences between calculated and observed temperature and humidity conditions shown in this report for seven different shelters.

The second uncertainty is closely related to the first, and concerns the reliability of input data. It is almost impossible to acquire complete three-dimensional information on earth thermal properties and temperature, and if such information were available, it would be difficult to use as computer imput data. Therefore, when a homogeneous heat conduction model is employed for a system surrounded by earth of heterogeneous characteristics and temperature, the choice of proper input values becomes very difficult. The uncertainty involved in evaluating the interior surface heat transfer coefficients is equally as difficult, as discussed in section 5.

Thus the simplification of the physical characteristics of the real shelter-earth system employed in creating an analytical model and the uncertainties in the thermal properties of the materials involved, became the principal approximations incorporated into the computer

analysis of the thermal environment in shelters. In spite of these uncertainties, good agreement between computed and observed results was achieved for many of the shelters descirbed in this report.

In addition to these general comments, these specific conclusions are emphasized, as follows:

(a) Soil analysis of most of the prototype shelters indicated that thermal diffusivity and thermal conductivity are in the neighborhood of 0.02 ft^2/hr and 0.75 Btu/hr ft^2 (deg F/ft), respectively. These values, in turn, seem to result in fairly good agreement of earth temperature change during the test period for most of the shelters.

(b) Heat conductance at the shelter inner surfaces for most of the summer shelter conditions may be approximated by the following:

1.0 Btu/hr ft^2 deg F for vertical walls.

1.5 Btu/hr ft^2 deg F for the ceiling.

0.5 Btu/hr ft^2 deg F for the floor.

Although there may be some other values and other combinations of these values that may have resulted in a slightly better simulation than those used in the analysis, these three values can be considered representative design heat transfer coefficients in the underground cavities.

(c) For large shelters, the one-dimensional, compound 6-directional model M-(3) will probably be adequate for calculating the shelter heat transfer. Thus, the complicated 3-dimensional model may not be required, at least for the heat transfer calculation of less than 14-day occupancy. For small shelters (such as a family shelter similar to the NBS shelter), however, it is recommended that the three-dimensional model be used for the accurate calculations.

7. APPENDIX

7.1 Air-conditioning subroutine.

Program M-(4) employs a subroutine for air conditioning the shelter. This subroutine enables the computer program to include the heat and vapor absorbing capacity of a given cooling system (a fan-and-coil unit) in the shelter heat balance equation of 2.1. The row by row account of the cooling coil performance is considered for the cross-counter flow circuited coil circulating the well water. The input data required for this subroutine are:

Shelter air dry-bulb temperature, t_a	^{o}F
Shelter air wet-bulb temperature, t_a'	^{o}F
Ventilation air dry-bulb temperature, t_v	^{o}F
Ventilation air wet-bulb temperature, T_v'	^{o}F
Inlet coolant temperature, t_w	^{o}F
Recirculation air rate, CFM_R	
Contact factor of air conditioning coil per row, C_f	
Thermal resistance between the solid-air interface and the coolant, R_w	^{o}F, ft^2 hr/Btu
Estimated temperature rise due to fan heat, Δt_F	
Coolant heat content, G_w	Btu/hr, ^{o}F

The contact factor per row C_f, mentioned above, is a function of air face velocity across the given air cooling coil, air-side heat transfer coefficient of the coil surface, and the amount of total heat transfer surface. The factor may be estimated by the following expressions:

$$C_f = 1 - e^{-\left(\frac{f_a S_p}{1.08\ CFM_t}\right)} \qquad 7\text{-}1$$

where f_a = air side heat transfer coefficient, Btu/hr ft^2 °F.

S_p = air side heat transfer surface of the coil per row, ft^2

CFM_t = CFM_{Rt} + CFM = total air flow rate.

The thermal resistance value R_w may be estimated by the following expression:

$$\frac{1}{R_w} = \frac{S_p}{S_t}\frac{1}{f_w} + \Sigma r \qquad 7\text{-}2$$

where S_t = coolant side heat transfer surface of the coil per row, ft^2

f_w = heat transfer coefficient of coolant, Btu/hr, ft^2 °F.

Σr = sum of all other heat resistance between the coolant side surface and air side surface, such as thermal resistance due to tube wall, finish bond, finish metal (depending upon the effectiveness of finish). and condensate film thickness.

The temperature rise due to fan heat can be estimated by total power input to the fan and air flow rate, assuming that all the fan heat will be expended to raise the air stream temperature. The value of Δt_f usually does not exceed 3 °F.

The coolant heat G_w is the coolant mass flow rate multiplied by the coolant specific heat. In the case of a direct expansion refrigerant coil, where the coolant temperature change in the coil is very small, G_w is considered infinity, or a very large number. The details of the cal-

culative procedure on C_f and R_w, and their design value can be found in references 5 and 6.

First, the air inlet condition to the air cooling coil is calculated by the following equation:

$$t_i = \frac{(CFM)_R(t_a) + (CFM)(t_v)}{CFM_R + CFM} \qquad 7\text{-}3$$

$$W_i = \frac{(CFM)_R(W_a) + (CFM)(W_v)}{(CFM)_R + CFM} \qquad 7\text{-}4$$

where t_i, W_i, W_a, and W_v represent inlet air dry-bulb temperatures, inlet air humidity ratio, shelter air humidity ratio, and ventilation air humidity ratio, respectively. These humidity ratio values are calculated by a separate subroutine from dry- and wet-bulb temperatures, as explained in section 2.7.

The air conditioning coil is assumed to be of multi-row structure, and the overall direction of coolant is counter to that of air flow, although for individual rows the coolant is flowing perpendicular to the air stream. For simplicity, it is assumed that the coolant temperature, as well as air-side surface temperature of a row, changes by a step function. The heat and vapor transfer calculation of the counter-flow dehumidifying coil requires an iterative procedure, because, except for the direct expansion coil, the outlet condition of air or coolant is not previously known. In this report, the outlet coolant temperature, which is in the same side as the inlet air condition of the coil, is first approximated. The heat and vapor transfer, and subsequent reduction of air temperature,

air humidity, and change of the coolant fluid, are then calculated row by row. After the calculation is completed, the total net change in coolant temperature is subtracted from the outlet temperature of the coolant, yielding the calculated coolant temperature at the inlet condition. If the calculated coolant temperature at the coil coolant inlet is different from the actual, the calculation is repeated with a modified outlet coolant temperature until the calculated agrees with the given inlet temperature of the coolant flow. The general heat and vapor transfer relation used for this calculation is described for i row as follows:

$$C_f \left[1.08\ CFM(t_i - t_{si}) + 4.5\ (CFM)(\lambda)(W_i - W_{si}) \right] = \frac{S_p}{R_w}(t_{si} - t_{wi}) \qquad 7\text{-}5$$

W_{si} in the above equation is the humidity ratio of the air saturated at the surface temperature, t_{si}; if $W_i \leq W_{si}$, the second term in the left hand side of the equation is set equal to zero. Since W_{si} is a complicated function of t_{si}, an iterative technique is required to solve t_{si} from the above expression. After t_{si} is obtained, the leaving air condition, t_{i+1}, W_{i+1}, from the i row, and entering coolant condition to the i + 1, $t_{w,i+1}$, are calculated by the following relations:

$$t_i - t_{i+1} = (t_i - t_s)(C_f) \qquad 7\text{-}6$$

$$\begin{aligned} W_i - W_{i+1} &= (W_i - W_{si})(C_f) \quad \text{if } W_i > W_{si} \\ &= 0 \qquad\qquad\qquad\quad \text{if } W_i \leq W_{si} \end{aligned} \qquad 7\text{-}7$$

$$\frac{S_p}{R_w}(t_{si} - t_{wi}) = (t_{wi} - t_{wi+1})(G_w) \qquad 7\text{-}8$$

Since all of the relations are linear, calculations of t_{i+1}, W_{i+1}, and $t_{w,i+1}$ are straightforward.

When the total number of rows is N and the properties in the air inlet point are specified by subscript 1, the properties of the air outlet condition should be specified by N + 1. Thus, the calculations will be iterated, as mentioned before, until $t_{w,N+1}$ becomes equal to t_w. The final results of the air conditioning capacity will be expressed as follows:

(1) Sensible cooling capacity, $Q_{AS} = (1.08)(CFM)(t_1 - t_{N+1} + \Delta t_f)$

(2) Latent cooling capacity, $Q_{AL} = (4.5)(CFM)(W_1 - W_{N+1})\lambda$.

With the value of Q_{AS} and Q_{AL} known, the shelter air condition for the next time period now can be calculated by adding Q_{AS} and Q_{AL} to the overall heat balance equation in (1).

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Reading shelter	Feb. 25, 1963 - Mar. 18, 1963
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Computer Programs

Fortran listings of the computer programs developed for the heat transfer studies in underground protective shelters during the contract research are attached in the following pages. Except for M-3 program, the computer symbols are explained according to input and output sequences at the beginning of each program.

A complete set of input data and illustrative examples of output format for program M-4 are also shown.

Program M-1 Input and Output Symbols

KP1: A matrix index marking the interface of earth and north wall.

KP2: A matrix index marking the interface of earth and south wall.

KP3: A matrix index marking the end of earth block outside the south wall.

KQ1: A matrix index marking the interface of earth and east wall.

KQ2: A matrix index marking the interface of earth and west wall.

KQ3: A matrix index marking the end of earth block outside the west wall.

KR1: A matrix index marking the interface of earth and shelter roof.

KR2: A matrix index marking the interface of earth and shelter floor.

KR3: A matrix index marking the end of earth block below the shelter floor.

KP: Nearest integer to (KP1 + KP2)/2.

KQ: Nearest integer to (KQ1 + KQ2)/2.

KR: Nearest integer to (KR1 + KR2)/2.

NN: Number of time increments.

LC: Number of matrix points for shelter inner-wall.

WC: Work cell for determining type of initial earth temperature data.

WC = -1. : Depthwise variation
   = 0. : Homogeneous earth temperature
   = 1. : Six directional variations.

TGI: A constant initial earth temperature when WC = 0.

TG1(I), TG2(I), TG3(I), TG4(I), TG5(I), TG6(I): Initial earth temperature profiles in earth blocks outside of north, south, east, west, roof and floor, respectively. °F

TC(L,M): Initial temperature distribution of the shelter inner wall, °F.

S(M): Shelter inner wall surface area, ft^2.

D(M): Thickness of shelter inner wall, ft.

ZL(M): Thickness of the earth block, ft.

CK(M): Thermal conductivity of shelter wall, Btu/hr,ft,°F

CG(M): Thermal conductivity of earth block, Btu/hr,ft,°F

AC(M): Thermal diffusivity of shelter wall, ft^2/hr.

AG(M): Thermal diffusivity of earth block, ft^2/hr.

H(M): Heat transfer coefficient at the shelter inner surface, Btu/hr,ft^2,°F.

HD(M): Mass transfer coefficient at the shelter inner surface, lb/hr, ft^2(lb/lb).

HG(H): Heat transfer coefficient at the external side of the earth block, Btu/hr, ft^2, °F.

DB(N): Outdoor air dry-bulb temperature, °F.

TV(CN): Ventilation air dry-bulb temperature, °F.

DPV(N): Ventilation air dew-point temperature, °F.

Q(N): Solar radiation, Btu/hr,ft^2.

A: Shelter length (internal dimension), ft.

B: Shelter width (internal dimension), ft.

C: Shelter height (internal dimension), ft.

ZN1: Number of 600 Btu/hr occupants.

ZN2: Number of 400 Btu/hr occupants

ZN3: Number of 200 Btu/hr occupants

TA: Shelter air temperature, °F.

DPA: Shelter air dew-point temperature, °F.

PB: Barometric pressure, in. Hg.

BS: Total sensible heat emitted by non-human heat source, Btu/hr

BL: Total latent heat generated by non-human heat source, Btu/hr.

DGX: Finite Difference, earth length for N-S. Coordinate direction, ft.

DGY: Finite Difference, earth length for E-W. Coordinate direction, ft.

DGZ: Finite Difference, earth length for roof-floor coordinate direction, ft.

DGX1: Modification of DGX for KP1 <I <KP2, ft.

DGY1: Modification of DGY for KR1 <J <KR2, ft.

DT: Finite difference inner wall time, hr.

V: Total interior volume of the shelter, cu ft.

G: Ventilation air rate, cfm.

ZN: Run identification number.

DTT: Finite difference time for earth block, hr.

TG(I,J,K) : Earth temperature °F.

N: Number of time iterations (subscript).

TM: Elapsed time, hr.

QVS: Sensible Heat Exchanged with Ventilation Air, Btu/hr.

QVL: Latent Heat Exchanged with Ventilation Air, Btu/hr.

QGS: Sensible Heat Generated within the shelter, Btu/hr.

QGL: Latent Heat Generated within the shelter, Btu/hr

QWST: Heat Transferred to the shelter inner surfaces, Btu/hr.

QWLT: Latent Heat Transferred to the shelter inner surfaces, Btu/hr.

TWCT: Water Vapor Collected on the shelter inner surfaces, lb/hr.

TQVS, TQVL, TQGS, TQGL, TQWST, TQWCT, TTWCT: Cumulative values for QVS, QVL, QGS, QGL, QWST, QWLT and TWCT, respectively.

AT(N) = TA Calculated shelter air dry-bulb temperature, °F.

RH(N) = RHA: Calculated shelter air relative humidity, %.

DP(N) = DPA: Calculated shelter air dew-point temperature, °F.

Subscript M refers to exposures such that

M = 1: North wall and its region

2: South wall and its region

3: East wall and its region

4: West wall and its region

5: Roof and its region

6: Floor and its region.

Subroutine:

GN: Computes the moisture saturated air vapor pressure for a given temperature using Goff and Gratch formula.

FN: Computes the boundary temperature by a finite difference formula.

QC: Computes the human metabolic heat by type of occupants as function of temperature.

```
C     UNDERGROUND FALLOUT SHELTER THERMAL ENVIRONMENT HEAT TRANSFER         1185000C
C     NATIONAL BUREAU OF STANDARDS PROJECT-10436   T.KUSUDA, 10.3           11850010
      DIMENSION TG(23,22,29),TC(10,6),QSUN(170,6),DB(170),TV(170)
      DIMENSION  DPV(170),TG1(10),TG2(10),TG3(10),TG4(10),TG5(10)          1185003C
      DIMENSION  TG6(10),TGO(30),S(6),D(6),ZL(6),AG(6),AC(6),CK(6),CG(6)1185004C
      DIMENSION  H(6),HD(6),HG(6),QWS(6),QWL(6),TQWS(6),TQWL(6),TWC(6)    1185005C
      DIMENSICN  TTWC(6),QSUNT(6), AT(170),RH(170),DP(170),QSUNO(6)        1185006C
      DIMENSION CD(6),E(6),Q(170)
    3 FORMAT(8F9.4)                                                         1185007C
    1 FORMAT(14I4,2F3.0)                                                    11851
   99 READ 1,KP1,KP2,KP3,KQ1,KQ2,KQ3,KR1,KR2,KR3,KP,KQ,KR,NN,LC,WC         11851
      IF(WC) 2, 12,11                                                       1185010C
   12 READ 3,TGI                                                            1185011C
      GO TO 10                                                              1185012C
    2 GO TO 13                                                              1185013C
   11 READ 3,(TG1(I),I=1,KP1),(TG2(I),I=KP2,KP3),(TG3(J),J=1,KQ1)          1185014C
      READ 3,(TG4(J),J=KQ2,KC3),(TG5(K),K=1,KR1),(TG6(K),K=KR2,KR3)        1185015C
   10 READ 3,((TC(L,M),L=1,LC),M=1,6)                                       11851
      READ 3,(S(M),M=1,6),(D(M),M=1,6),(ZL(M),M=1,6),(CK(M),M=1,6)         1185017C
      READ 3,(CG(M),M=1,6),(AC(M),M=1,6),(AG(M),M=1,6),(H(M),M=1,6)        1185018C
      READ 3,(HD(M),M=1,6),(HG(M),M=1,6)                                    1185019C
    6 READ 3,(DB(N),N=1,NN),(TV(N),N=1,NN),(DPV(N),N=1,NN),(Q(N),N=1,NN)1185040C
      DO  55     M=1,6                                                      1185041C
      IF(HG(M))50,51,50                                                     1185042C
   51 DO  52   N=1,NN                                                       1185043C
   52 QSUN(N,M)=0.                                                          1185044C
      GO TO 55                                                              1185045C
   50 DO 54  N=1,NN                                                         1185046C
   54 QSUN(N,M)=Q(N)                                                        1185047C
   55 CONTINUE                                                              1185048C
    9 READ 3,A,B,C,ZN1,ZN2,ZN3,TA,DPA,PB,BS,BL,DGX,DGY,DGZ,DGX1,DGY1,DT    1185049C
   14 FORMAT(4F9.4)                                                         11851
      READ 14,V,G,ZN,DTT                                                    11851
      GO TO 300                                                             1185052C
   13 READ 3,(TGC(K),K=1,KR3)                                               1185053C
      GO TO 10                                                              1185054C
   15 FORMAT(43H1            UNDERGROUND FALLOUT SHELTER DATA)              1185055C
  300 PRINT 15                                                              1185056C
      PRINT 16                                                              1185057C
   16 FORMAT(79H0       ZN        A         B         C          V          G 1185058C
     1      ZN1   ZN2   ZN3     DT)                                         1185059C
   30 FORMAT(F9.0,F7.1,2F8.1,F10.0,F12.0,F7.0,3F6.2)
      PRINT 30,ZN,A,B,C,V,G,ZN1,ZN2,ZN3,DT                                  1185059:
      PRINT 17                                                              1185060C
   17 FORMAT(64H0    M          1         2         3         4         5   1185061C
     1       6)                                                             1185062C
      PRINT 18,(CK(M),M=1,6 )                                               1185063C
   18 FORMAT(10H0 CK(M)     6F10.3)                                         1185064C
   19 FORMAT(10H0 CG(M)     6F10.3)                                         1185065C
   20 FORMAT(10H0 AC(M)     6F10.3)                                         1185066C
   21 FORMAT(10H0 AG(M)     6F10.3)                                         1185067C
   22 FORMAT(10H0   D(M)    6F10.3)                                         1185068C
   23 FORMAT(10H0  ZL(M)    6F10.3)                                         1185069C
   24 FORMAT(10H0   S(M)    6F10.3)                                         1185070C
   25 FORMAT(10H0   H(M)    6F10.3)                                         1185071C
   26 FORMAT(10H0 HG(M)     6F10.3)                                         1185072C
   27 FORMAT(10H0 HD(M)     6F10.3)                                         1185073
      PRINT19,(CG(M),M=1,6)                                                 1185074
      PRINT20,(AC(M),M=1,6)                                                 1185075
      PRINT21,(AC(M),M=1,6)                                                 1185076
```

```
      PRINT22,(D(M), M=1,6)
      PRINT23,(ZL(M),M=1,6)
      PRINT24,(S(M), M=1,6)
      PRINT25,(H(M), M=1,6)
      PRINT26,(HG(M),M=1,6)
      PRINT27,(HD(M),M=1,6)
      GO TO 100
C  GROUND TEMPERATURE INITIALIZATION
  100 IF(WC) 101,102,103
  101 DO 104  I=1,KP3
      DO 104  J=1,KQ3
      DO 104  K=1,KR3
  104 TG(I,J,K)=TGO(K)
      GO TO 129
  102 DO 105  I=1,KP3
      DO 105  J=1,KQ3
      DO 105  K=1,KR3
  105 TG(I,J,K)=TGI
      GO TO 129
  103 DO 900  I=1,KP3
      DO 900  J=1,KQ3
      DO 900  K=1,KR3
      IF(KP1-I) 111,106,106
  106 IF(J-KC1) 111,107,107
  107 IF(KQ2-J) 111,108,108
  108 IF(K-KR1) 111,109,109
  109 IF(KR2-K) 111,110,110
  110 TG(I,J,K) =TG1(I)
      GO TO 900
  111 IF(I-KP2) 117,112,112
  112 IF(J-KC1) 117,113,113
  113 IF(KQ2-J) 117,114,114
  114 IF(K-KR1) 117,115,115
  115 IF(KR2-K) 117,116,116
  116 TG(I,J,K) =TG2(I)
      GO TO 900
  117 IF(KQ1-J) 121,118,118
  118 IF(K-KR1) 121,119,119
  119 IF(KR2-K) 121,120,120
  120 TG(I,J,K)=TG3(J)
      GO TO 900
  121 IF(J-KC2) 125,122,122
  122 IF(K-KR1) 125,123,123
  123 IF(KR2-K) 125,124,124
  124 TG(I,J,K)=TG4(J)
      GO TO 900
  125 IF(KR1-K) 127,126,126
  126 TG(I,J,K)=TG5(K)
      GO TO 900
  127 IF(K-KR2) 900,128,128
  128 TG(I,J,K)=TG6(K)
  900 CONTINUE
 1900 FORMAT(10F9.5)
  129 TM=0.0
      TQWST=0.
      TQWLT=0.
      TTWCT=0.
      TQVS=0.
      TQVL=0.
      TQGS=0.
```

```
      TQGL=0.
      TTQSUN=0.
      DO 152  M=1,6
      TQWS(M)=0.
      TQWL(M)=0.
      TTWC(M)=0.
  152 QSUNT(M)=0.
      LLC=LC-1
      ZLC=LLC
C END OF INITIALIZATION
      DO  800 N=1,NN
   29 FORMAT (10F5.1)
  301 DO 28     M=1,6
   28 PRINT 29, (TC(L,M),L=1,LC)
      PRINT 29, (TG(I,KQ,KR),I=1,KP1)
      PRINT 29, (TG(I,KQ,KR),I=KP2,KP3)
      PRINT 29, (TG(KP,J,KR),J=1,KQ1)
      PRINT 29, (TG(KP,J,KR),J=KQ2,KQ3)
      PRINT 29, (TG(KP,KQ,K),K=1,KR1)
      PRINT 29, (TG(KP,KQ,K),K=KR2,KR3)
 1501 FORMAT(16F5.1)
      PRINT 1501, TG(1,1,1),TG(1,1,KR3),TG(1,KQ3,1),TG(1,KQ3,KR3),TG(KP3
     1,1,1),TG(KP3,1,KR3),TG(KP3,KQ3,1),TG(KP3,KQ3,KR3),TG(KP1,KQ1,KR1),
     1TG(KP1,KQ1,KR2),TG(KP1,KQ2,KR1),TG(KP1,KQ2,KR2),TG(KP2,KQ1,KR1),TG
     1(KP2,KQ1,KR2),TG(KP2,KQ2,KR1),TG(KP2,KQ2,KR2)
      TM=TM+DTT
      PSV=GN(DPV(N))
      WV=0.622*PSV/(PB-PSV)
      DTM=0.
 1..J5 DTM=DTM+DT
      DTA=0.2
      TA1=40.0
      IR=1
  405 QVS=1.08*G*(TA1-TV(N))
      QGS=QG(TA1,ZN1,ZN2,ZN3,1.)+BS
      QWST=0.
      DO  153  M=1,6
      DD(M)=D(M)/ZLC
      QWS(M)=H(M)*S(M)*(TA1-TC(1,M))
  153 QWST=QWST+QWS(M)
      GO TO (1153,406),IR
 1153 ZX=QGS-QVS-QWST
      IF(ZX) 400,401,402
  402 TA1=TA1+DTA
      ZX2=ABSF(ZX)
      GO TO 405
  400 TA2=TA1-DTA
      ZX1=ABSF(ZX)
      TA=(TA1*ZX2+TA2*ZX1)/(ZX1+ZX2)
      IR=2
      TA1=TA
      GO TO 405
  401 TA=TA1
  406 DDPA=0.2
      DPA1=40.0
      IR=1
  409 PSA=GN(DPA1)
      WA=0.622*PSA/(PB-PSA)
      QVL=4780.*G*(WA-WV)
      QWLT=0.
      TWCT=0.
      DO  158     M=1,6
```

```
  157 PSW=GN(TC(1,M))                                                    1185162
      WS=0.622*PSW/(PB-PSW)                                              1185162
      IF(WA-WS) 154,154,155                                              1185163
  154 QWL(M)=0.                                                          1185163
      GO TO 156                                                          1185164
  155 QWL(M)=1061.*HD(M)*S(M)*(WA-WS)                                    1185164
  156 QWLT=QWLT+QWL(M)                                                   1185168
      TWC(M)=QWL(M)/1061.                                                1185169
  158 TWCT=TWCT+TWC(M)                                                   1185169
      QGL=QG(TA,ZN1,ZN2,ZN3,0.)+BL                                       1185170
      GO TO (1158,413),IR                                                11851
 1158 ZY=QGL-QVL-QWLT                                                    11851
      IF(ZY) 410,411,412
  412 DPA1=DPA1+CDPA
      ZY2=ABSF(ZY)
      GO TO 409
  410 DPA2=DPA1-CDPA
      ZY1=ABSF(ZY)
      DPA=(DPA1*ZY2+DPA2*ZY1)/(ZY1+ZY2)
      IR=2                                                               11851
      DPA1=DPA
      GO TO 409                                                          11851
  411 DPA=DPA1
  413 POA=GN(TA)
      RHA=100.*PSA/POA                                                   1185175
      DO  161 M=1,6                                                      1185176
      TQWS(M)=TQWS(M)+QWS(M)*DT                                          1185176
      TQWL(M)=TQWL(M)+QWL(M)*DT                                          1185177
      ZW=CD(M)*(QWS(M)+QWL(M))/(CK(M)*S(M))+TC(2,M)                      1185165
  160 TC(1,M)=ZW                                                         1185166
  161 TTWC(M)=TTWC(M)+TWC(M)*DT                                          1185177
      TQWST=TQWST+QWST*DT                                                1185178
      TQWLT=TQWLT+QWLT*DT                                                1185178
      TTWCT=TTWCT+TWCT*DT                                                1185179
      TQGS=TQGS+QGS*DT                                                   1185179
      TQGL=TQGL+QGL*DT                                                   1185180
      TQVS=TQVS+QVS*DT                                                   1185180
      TQVL=TQVL+QVL*DT                                                   1185181
C CONCRETE WALL TEMPERATURE DISTRIBUTION                                  1185202
      DO 164  M=1,6                                                      1185203
      E(M)=AC(M)*DT/DD(M)**2                                             1185204
      DO  164  L=2,LLC                                                   11851
  164 TC(L,M)=E(M)*(TC(L-1,M)+TC(L+1,M)+(1./E(M)-2.)*TC(L,M))            1185206
      IF(DTM-DTT) 1405,1164,1164                                         11851
C GROUND AND CONCRETE BOUNDARY TEMPERATURES                               1185207
 1164 DO 165 J=KQ1,KQ2                                                   11851
      DO 165 K=KR1,KR2                                                   1185209
      TG(KP1,J,K) =FN(CK(1),CG(1),TC(LLC,1),TG(KP1-1,J,K), DD(1),DGX,0.)11851
  165 TG(KP2,J,K) =FN(CK(2),CG(2),TC(LLC,2),TG(KP2+1,J,K), DD(2),DGX,0.)11851
      DO 166  I=KP1,KP2                                                  1185212
      DO 166  K=KR1,KR2                                                  1185213
      TG(I,KQ1,K) =FN(CK(3),CG(3),TC(LLC,3),TG(I,KQ1-1,K), DD(3),DGY,0.)11851
  166 TG(I,KQ2,K) =FN(CK(4),CG(4),TC(LLC,4),TG(I,KQ2+1,K), DD(4),DGY,0.)11851
      DO 167  I=KP1,KP2                                                  1185216
      DO 167  J=KQ1,KQ2                                                  1185217
      TG(I,J,KR1) =FN(CK(5),CG(5),TC(LLC,5),TG(I,J,KR1-1), DD(5),DGZ,0.)11851
  167 TG(I,J,KR2) =FN(CK(6),CG(6),TC(LLC,6),TG(I,J,KR2+1), DD(6),DGZ,0.)11851
      TC(LC,1)=TG(KP1,KQ,KR)                                             11851
      TC(LC,2)=TG(KP2,KQ,KR)                                             11851
      TC(LC,3)=TG(KP,KQ1,KR)                                             11851
      TC(LC,4)=TG(KP,KQ2,KR)                                             11851
      TC(LC,5)=TG(KP,KQ,KR1)                                             11851
      TC(LC,6)=TG(KP,KQ,KR2)                                             11851
      PRINT 1900,(TC(LC,M),M=1,6)
```

```
C   GROUND TEMPERATURES                                              1185220
       KP4 = KP3-1                                                   1185220
       KQ4 = KQ3-1                                                   1185220
       KR4 = KR3-1                                                   1185220
       DO  600   I=2,KP4                                             1185221
       DO 600    J=2,KQ4                                             1185222
       DO 600    K=2,KR4                                             1185223
       IF(KP1-I)  173,168,168                                        1185224
   168 IF(J-KQ1)  173,169,169                                        1185225
   169 IF(KQ2-J)  173,170,170                                        1185226
   170 IF(K-KR1)  173,171,171                                        1185227
   171 IF(KR2-K)  173,172,172                                        1185228
   172 AGG=AG(1)                                                     1185229
       IF(I-KP1) 500,600,600
   173 IF(I-KP2)  179,174,174                                        1185231
   174 IF(J-KQ1)  179,175,175                                        1185232
   175 IF(KQ2-J)  179,176,176                                        1185233
   176 IF(K-KR1)  179,177,177                                        1185234
   177 IF(KR2-K)  179,178,178                                        1185235
   178 AGG=AG(2)                                                     1185236
       IF(KP2-I) 500,600,600
   179 IF(KQ1-J)  183,180,180                                        1185238
   180 IF(K-KR1)  183,181,181                                        1185239
   181 IF(KR2-K)  183,182,182                                        1185240
   182 AGG=AG(3)                                                     1185241
       IF(J-KQ1) 500,590,590
   590 IF(I-KP1) 500,580,580
   580 IF (KP2-I) 500,600,600
   183 IF(J-KQ2)  187,184,184                                        1185243
   184 IF(K-KR1)  187,185,185                                        1185244
   185 IF(KR2-K)  187,186,186                                        1185245
   186 AGG=AG(4)                                                     1185246
       IF (KQ2-J) 500,570,570
   570 IF (I-KP1) 500,560,560
   560 IF(KP2-I) 500,600,600
   187 IF(KR1-K)  189,188,188                                        1185248
   188 AGG=AG(5)                                                     1185249
       IF (K-KR1) 500,550,550
   550 IF (I-KP1) 500,540,540
   540 IF (J-KQ1) 500,530,530
   530 IF (KQ2-J) 500,520,520
   520 IF(KP2-I) 500,600,600
   189 IF(K-KR2)  600,190,190                                        1185251
   190 AGG=AG(6)                                                     1185252
       IF(KR2-K) 500,521,521
   521 IF (I-KP1) 500,522,522
   522 IF(J-KQ1) 500,523,523
   523 IF(KQ2-J) 500,524,524
   524 IF(KP2-I) 500,600,600
   500 IF(I-KP1) 502,502,503                                         1185252
   503 IF(KP2-I) 502,502,504                                         1185252
   504 DGX=DGX1                                                      1185252
   502 IF(J-KQ1) 501,501,505                                         1185252
   505 IF(KQ2-J) 501,501,506                                         1185252
     6 DGY=DGY1                                                      1185252
   501 EGX=AGG*DTT/(DGX**2)                                          11851
       EGY=AGG*DTT/(DGY**2)                                          11851
       EGZ=AGG*DTT/(DGZ**2)                                          11851
       T1=TG(I-1,J,K)                                                1185256
       T2=TG(I+1,J,K)                                                1185257
```

```
      T3=TG(I,J-1,K)
      T4=TG(I,J+1,K)
      T5=TG(I,J,K-1)
      T6=TG(I,J,K+1)
      XX=EGX*(T1+T2)+EGY*(T3+T4)+EGZ*(T5+T6)
      YY=1.-2.*(EGX+EGY+EGZ)
      TG(I,J,K)=XX+TG(I,J,K)*YY
  600 CONTINUE
C GROUND SURFACE TEMPERATURES
      DO 191  J=1,KQ3
      DO 191  K=1,KR3
      TG(1,J,K)=FN(HG(1),CG(1),DB(N),TG(2,J,K),1.,DGX,QSUN(N,1))
  191 TG(KP3,J,K)=FN(HG(2),CG(2),DB(N),TG(KP3-1,J,K),1.,DGX,QSUN(N,2))
      DO 192  I=1,KP3
      DO 192  K=1,KR3
      TG(I, 1, K)=FN(HG(3),CG(3),DB(N),TG(I,  2,  K),1.,DGY,QSUN(N,3))
  192 TG(I,KQ3,K)=FN(HG(4),CG(4),DB(N),TG(I,KQ3-1,K),1.,DGY,QSUN(N,4))
      DO 193  I=1,KP3
      DO 193  J=1,KQ3
      TG(I,J,  1)=FN(HG(5),CG(5),DB(N),TG(I, J,   2),1.,DGZ,QSUN(N,5))
  193 TG(I,J,KR3)=TG(I,J,KR3)





      AT(N)=TA
      RH(N)=RHA
      DP(N)=DPA
      WRITE OUTPUT TAPE 81,29,(TC(1,M),M=1,6),TG(1,1,1),TG(1,1,KR3)
      WRITE OUTPUT TAPE 81,1900,TM
  195 FORMAT(10H0   QWS(M)   6F15.0)
  196 FORMAT(10H0  TQWS(M)   6F15.0)
  197 FORMAT(10H0   QWL(M)   6F15.0)
  198 FORMAT(10H0  TQWL(M)   6F15.0)
  199 FORMAT(10H0   TWC(M)   6F15.0)
  200 FORMAT(10H0  TTWC(M)   6F15.0)
  201 FORMAT(10H0  TC(1,M)   6F15.1)
  202 FORMAT(100H0                 1                 2                 3
     1          4              5              6              )
  203 FORMAT(100H1   N     TM              QVS               QVL              QGS
     1           QGL              QWST             QWLT )
  204 FORMAT(100H                TWCT             TQVS              TQVL
     1 TQGS             TQGL             TQWST             )
  205 FORMAT(100H                TQWLT             TTWCT             TQSUN
     1TTQSUN                                                 )
  206 FORMAT(1I 3,1F6.1,6F15.0)
  207 FORMAT(6F 15.2)
  208 FORMAT(5F 15.0)
  302 PRINT 203
      PRINT 206, N,TM,QVS,QVL,QGS,QGL,QWST,QWLT
      PRINT 204
      PRINT 207, TWCT,TQVS,TQVL,TQGS,TQGL,TQWST
      PRINT 205
      PRINT 208, TQWLT,TTWCT,TQSUN,TTQSUN
      PRINT 202
      PRINT 195,(QWS(M),M=1,6)
      PRINT 196,(TQWS(M),M=1,6)
      PRINT 197,(QWL(M),M=1,6)
      PRINT 198,(TQWL(M),M=1,6)
```

```
      PRINT 199,(TWC(M),M=1,6)
      PRINT 200,(TTWC(M),M=1,6)                                         1185317
      PRINT 201,(TC(1,M),M=1,6)                                         1185318
      PRINT 209                                                         1185319
  209 FORMAT(100H                  TV(N)               DPV(N)               DB(N)        1185320
     1     TA                DPA                RHA                     1185320
      PRINT 29, AT(N),DP(M),RH(N)                                       1185320
  800 PRINT 207,TV(N),DPV(N),DB(N),TA,DPA,RHA
  801 DIMENSION AA(2),BB(2),TN(170)                                     1185320
  303 AA(1)=0.0                                                         1185340
      AA(2)=500.                                                        1185340
      BB(1)=100.                                                        11851
      BB(2)=50.                                                         1185340
      TM=0.                                                             1185340
      DO  90   N=1,  NN                                                 1185340
      TM=TM+DTT                                                         1185340
   90 TN(N)=TM
      CALL PLOT (3,NN, TN,AT, NN,TN,DP,2,AA,BB)                         1185340
      CALL  SYSTEM                                                      1185340
      GOTO  99                                                          1185341
      END                                                               1185341
```

Program M-2 Input and Output Symbols

IX1: A matrix index marking the boundary between the shelter air space and surrounding earth (longitudinal direction)

IX2: A matrix index marking the end of earth region along the longitudinal direction.

IY1: A matrix index marking the boundary between the shelter air space and surrounding earth (transverse direction).

IY2: A matrix index marking the end of earth region along the transverse direction.

IZ1: A matrix index marking the boundary between the shelter air and roof earth region.

IZ2: A matrix index marking the boundary between the shelter air and floor earth region.

IZ3: A matrix index marking the end of earth of shelter floor region.

CG: Thermal conductivity of earth, Btu/hr,ft, °F.

AG: Thermal diffusivity of earth, ft^2/hr.

DT: Finite difference time, hr

DX: Finite difference length along the longitudinal direction, ft.

DY: Finite difference length along the transverse direction, ft.

DZ: Finite difference length along the vertical axis, ft.

DTG: Finite difference time for computing the ground surface heat exchange, (modification of DT), hr.

A, B, C: Internal dimensions of shelter, ft.

CFM: Shelter ventilation air, cu.ft/min.

HV = (60) (specific heat of air)(density of air) = 1.08 for standard air, Btu/hr, °F, CFM.

WG: Work cell for ground surface temperature calculation

if WG < 0, ground surface temperature = outdoor air temperature.

if WG > 0, ground surface temperature is computed by solar heat, convection heat and conduction heat.

RUN: Run number.

HW: Vertical wall surface heat transfer coefficients, Btu/hr, ft^2, °F.

HR: Ceiling surface heat transfer coefficient, Btu/hr, ft^2, °F.

HF: Floor surface heat transfer coefficient, Btu/hr, ft^2, °F.

HG: Ground surface heat transfer coefficient, Btu/hr, ft^2, °F.

TSW, TSR, TSF: Initial surface temperatures of wall, ceiling and floor respectively, °F.

TA: Shelter air temperature, °F.

DPA: Shelter air dew point temperature, °F.

ZN1: Number of 600 Btu/hr occupants.

ZN2: Number of 400 Btu/hr occupants.

Zn3: Number of 200 Btu/hr occupants.

BS: Sensible heat generated in the shelter by non-human source, Btu/hr.

BL: Latent heat generated in the shelter by non-human source, Btu/hr.

PB: Barometric pressure, in. hg.

L1: If positive, initial ground temperature varies with depth.

L2: If positive, outdoor thermal environment is constant.

L3: If positive, ground temperature will be printed out only at the end of total time iteration.

L4: If positive, ventilation air rate varies with time.

L5: If positive, number of 600 Btu/hr occupants varies with time.

L6: If positive, number of 400 Btu/hr occupants varies with time.

L7: If positive, number of 200 Btu/hr occupants varies with time.

L8: Strength of non-human heat source and sink will vary with time.

NN: Total number of time iterations.

ØPT2: Work cell for two different kinds of data input formats.

ZLW: Lewis number for wall = 1.

ZLR: Lewis number for roof = 1.

ZLF: Lewis number for floor = 1.

TGØØ: Constant initial earth temperature, when L1≤0, °F

TGØ(K): Depthwise variation of initial earth temperature when L1>0, °F.

DBØ: Constant outdoor air dry-bulb temperature, °F, when L2≤0.

TVØ: Constant ventilation air dry-bulb temperature, °F, when L2≤0.

QSUNØ: Constant solar radiation, Btu/hr, ft^2, when L2≤0.

DPVØ: Constant ventilation air dew-point temperature, °F, when L2≤0.

DB(N): Outdoor air dry-bulb temperature (time dependent), °F.

TV(N): Ventilation air dry-bulb temperature (time dependent), °F.

DPV(N): Ventilation air dew-point temperature (time dependent), °F.

QSUN(N): Solar irradiation (time dependent), Btu/hr ft^2.

DN(N): Ventilation air rate (time dependent), cfm.

ZN1N(N): Number of 600 Btu/hr occupants (time dependent).

ZN2N(N): Number of 400 Btu/hr occupants (time dependent).

QN3N(N): Number of 200 Btu/hr occupants (time dependent).

BSS(N): Sensible heat due non-human heat source (time dependent), Btu/hr.

BLL(N): Latent heat due non-human heat source (time dependent), Btu/hr.

QX: Heat flux on wall normal to longitudinal axis, Btu/hr ft^2.

QY: Heat flux on wall normal to transverse axis, Btu/hr ft^2.

QYF: Heat flux on ceiling surface, Btu/hr ft^2.

QZF: Heat flux on floor surface, Btu/hr ft^2.

TM: Elapsed time, hr.

STM(N): Mean surface temperature, °F.

ST1(N): Average temperature of the surface normal to longitudinal axis, °F.

ST2(N): Average temperature of the surface normal to transverse axis, °F.

ST3(N): Average surface temperature of ceiling, °F.

ST4(N): Average surface temperature of floor, °F.

RHA(N): Shelter air relative humidity, %.

TAA(N): Shelter air dry-bulb temperature, °F.

Y(N): Elapsed time = TM, hr.

```
C  SIMPLIFIED  SYMMETRIC SHELTER HEAT TRANSFER ANALYSIS  ,T.KUSUDA       118510
C  RECTANGULAR PARALLELEPIPED   SHALLOW  UNDERGROUND                      118510
C  S=TOTL SHELTER HEAT TRANSFER SURFACE, SQ,FT                            118510
C  CFM=VENTILATION AIR RATE ,HV=1.08 SENSIBLE                             118510
C  CG =TOTAL HEAT GENERATED INSIDE THE SHELTER                            118510
C  WG =WORK CELL, IF WG=0.,GROUND SURFACE=DB(N),IF NONZERO,CALCULATE      118510
C  IF  L1=0    TGO(K)=TGCC                                                118510
C  IF  L2=0   DB(N)=DBO, TV(N)=TVO, QSUN(N)=QSUNO                         118510
C  IF  L3=0   PRINT TEMPERATURE AT EVERY TIME INTERVAL                    118510
C  IF  L4=1  READ CFM FOR EACH TIME PERIOD                                118518
C  IF  L5=1  READ ZN1 FOR EACH TIME PERIOD                                118518
C  IF  L6=1  READ ZN2 FOR EACH TIME PERIOD                                118518
C  IF  L7=1  READ ZN3 FOR EACH TIME PERIOD                                118518
C     IF L8=1  READ BS AND BL FOR EACH TIME PERIOD                        118518
      DIMENSION STM(300),ST1(300),ST2(300),ST3(300),ST4(300)
      DIMENSION DPV(300),Y(300),EB(2),EC(2),RHA(300)
      DIMENSION T(20,20,40),TGO(40),DB(300),TV(300),QSUN(300)
      DIMENSION TAA(300),V(300),DN(300),ZN1N(300),ZN2N(300),ZN3N(300)
      DIMENSION  BSS(300),BLL(300)
  500 FORMAT(72H                                                          118518
     1                                                                   )118518
      READ 500                                                            118518
      PRINT 500                                                           118518
  201 FORMAT(10F7.0)                                                      118510
  202 FORMAT(10I7)                                                        118510
  199 READ 202,IX1,IX2,IY1,IY2,IZ1,IZ2,IZ3                                118510
      READ 201,CG,AG,CT,DX,DY,DZ,DTG,A,B,C                                118513
      READ 201,  CFM,HV,WG,RUN,HW,HR,HF,HG                                118513
      READ 201,TSW,TSR,TSF,TA,DPA                                         118513
      READ 201,ZN1,ZN2,ZN3,BS,BL,PB
      READ 202,L1,L2,L3,NN,L4, L5,L6,L7                                   118510
      READ 201, OPT2
      READ 201,ZLW,ZLR,ZLF
      IF(L1) 203,203,204                                                  118510
  203 READ 201,TGOO                                                       118510
      DO  205  K=1,IZ3                                                    118510
  205 TGO(K)=TGOO                                                         118510
      GO TO  206                                                          118510
  204 READ 201,(TGO(K),K=1,IZ3)                                           118510
  206 IF(L2) 207,207,208                                                  118510
  207 READ 201,DBO,TVO,QSUNO,DPVO                                         118510
      DO  209  N=1,NN                                                     118510
      DB(N)=DBO                                                           118510
      TV(N)=TVO                                                           118510
      DPV(N)=DPVO                                                         11851
  209 QSUN(N)=QSUNO                                                       118510
      GO TO 210                                                           118510
  208 IF(OPT2) 401,400,401
  400 READ 402,(DB(N),N=1,NN),(TV(N),N=1,NN),(DPV(N),N=1,NN),(QSUN(N),N=
     11,NN)
  402 FORMAT (8F9.0)
      GO TO 210
  401 READ 201,(DB(N),N=1,NN)
      READ 201,(TV(N),N=1,NN)                                             118510
      READ 201,(DPV(N),N=1,NN)                                            11851
      IF (WG) 61,61,60                                                    118518
   60 READ 201,(QSUN(N),N=1,NN)                                           118518
   61 IF (L4) 63,63,62                                                    118518
   62 READ 201,(DN(N),N=1,NN)                                             118518
   63 IF (L5) 65,65,64                                                    118518
```

```
   64 READ 201,(ZN1N(N),N=1,NN)
   65 IF (L6) 67,67,66                                                      118518
   66 READ 201,(ZN2N(N),N=1,NN)                                             118518
   67 IF(L7) 69,69,68                                                       118518
   68 READ 201,(ZN3N(N),N=1,NN)                                             118518
   69 READ 202, L8                                                          118518
      IF(L8)  210,210,70                                                    118518
   70 READ  201,(BSS(N),N=1,NN)                                             118518
      READ  201,(BLL(N),N=1,NN)                                             118518
  210 DO  300 K=1,IZ3                                                       118518
      DO  300 J=1,IY2                                                       118510
      DO  300 I=1,IX2                                                       118510
  211 IF(I-IX1) 212,216,216                                                 118510
  212 IF(J-IY1) 213,216,216                                                 118510
  213 IF(IZ1-K) 214,216,216                                                 118510
  214 IF(K-IZ2) 215,216,216                                                 118510
  215 GO TO 300                                                             118510
  216 T(I,J,K)=TGO(K)                                                       118510
  300 CONTINUE                                                              118510
      PRINT  217,RUN                                                        118510
  217 FORMAT(50H1 SYMMETRICAL SHELTER  HEAT TRANSFER,RUN            F3.0 )118510
      PRINT  218                                                            118510
  218 FORMAT(65H0               S          CFM          TA          HV          HW
     1   HG                                                             )118510
      SR=A*B                                                                118513
      SF=SR                                                                 118513
      SW=(A+B)*2.*C                                                         118513
      S=SW+SR+SF                                                            118513
      PRINT 219,S,CFM,TA,HV,HW,HG
  650 FORMAT(100H0          WG          HW          HR          HF          ZJW
     1  ZLR          ZLF          DX          DY          DZ                )
      PRINT 650
  651 FORMAT(10F10.3)
      PRINT 651,WG,HW,HR,HF,ZLW,ZLR,ZLF,DX,DY,DZ
  219 FORMAT(6F10.3)                                                        118510
      PRINT  220                                                            118510
  220 FORMAT(55H0     DB(N)       TV(N)     QSUN(N)                         )118510
      DO 222     N=1,NN                                                     118510
  222 PRINT  221, DB(N),TV(N),QSUN(N)                                       118510
  221 FORMAT(3F10.2)                                                        118510
      READ 202,II,JJ,KK
C END OF DATA  INPUT                                                        118510
      KX=IX2-1                                                              118510
      KXX=IX1-1                                                             118510
      KY=IY2-1                                                              118510
      KYY=IY1-1                                                             118510
      KZ=IZ3-1                                                              118510
      KZ1=IZ1-1                                                             118510
      KZ2=IZ2-1                                                             118510
      EX=AG*DT/(DX*DX)                                                      118510
      EY=AG*DT/(DY*DY)                                                      118510
      EZ=AG*DT/(DZ*DZ)                                                      118510
      H1=HW*DX/CG                                                           118510
      H2=HW*DY/CG                                                           118513
      H3 =HR*DZ/CG                                                          118513
      H4 =HF*DZ/CG                                                          118513
      HGU=HG*DZ/CG                                                          118513
      RO=1.-2.*(EX+EY+EZ)                                                   118510
      RX=RO-2.*EX*H1                                                        118510
      RY=RO-2.*EY*H2
```

```
      RZR=RO-2.*EZ*H3
      RZF=RO-2.*EZ*H4
      RG=1.-2.*(EZ)*(1.+HGU)*CTG/DT                                    118510
      TN=0.                                                            118510
C     END OF INITIALIZATION                                            118510
      PRINT 223                                                        118510
  223 FORMAT(100H0         RO         RX         RY        RZR        RZF 118510
     1    H1        H2        H3        H4                             )
      PRINT 229,RO,RX,RY,RZR,RZF,H1,H2,H3,H4
  329 PRINT 228
  228 FORMAT(105H          CG         AG        HGU         DX         DY 118510
     1    DZ        CT        EX        EY        EZ                   )118510
      PRINT 229,CG,AG,HGU  ,DX,DY,DZ,CT,EX,EY,EZ
  229 FORMAT(10F10.3)                                                  118510
  234 FORMAT(20F6.1)                                                   118510
      XX=IX1
      YY=IY1
      ZZ=IZ2-IZ1
      AA=CX*XX*2.
      BB=CY*YY*2.
      CC=CZ*ZZ
      SX=AA*CC
      SY=BB*CC
      SZR=AA*BB
      SZF=SZR
  612 FORMAT( 50H1         QX         QY        QZR        QZF         TM )118513
      PRINT 612                                                        118513
      WA=W(DPA)                                                        118513
      WW=W(TSW)                                                        118513
      WR=W(TSR)                                                        118513
      WF=W(TSF)                                                        118513
C     START OF TIME ITERATION                                          118510
      DO    907       N=1,NN                                           118510
      IF (L4) 51,51,50                                                 118518
   50 CFM = DN(N)                                                      118518
   51 IF (L5) 53,53,52                                                 118518
   52 ZN1 = ZN1N(N)                                                    118518
   53 IF (L6) 55,55,54                                                 118518
   54 ZN2 = ZN2N(N)                                                    118518
   55 IF(L7) 71,71,56                                                  118518
   56 ZN3 = ZN3N(N)                                                    118518
   71 IF(L8)   57,57,72                                                118518
   72 BS=BSS(N)                                                        118518
      BL=BLL(N)                                                        118518
   57 TM=TM+DT                                                         118510
      IF(WA-WW)601,601,602                                             118513
  602 ZZW=1061.*(WA-WW)/(TA-TSW+0.00001)/0.243                         118513
      ZZW=ZZW/ZLW
      GO TO 603                                                        118513
  601 ZZW=0.
  603 IF(WA-WR)604,604,605                                             118513
  605 ZZR=1061.*(WA-WR)/(TA-TSR+0.00001)/0.243                         118513
      ZZR=ZZR/ZLR
      GO TO 606                                                        118513
  604 ZZR=0.
  606 IF(WA-WF)607,607,608                                             118513
  608 ZZF=1061.*(WA-WF)/(TA-TSF+0.00001)/0.243                         118513
      ZZF=ZZF/ZLF
      GO TO 609                                                        118513
  607 ZZF=0.
```

```
609 TSM=(TSW*SW+TSR*SR+TSF*SF)/(SW+SR+SF)                          118513
    PW=TA
    PR=TA
    PF=TA
    HX=H1*(1.+ZZW)                                                 118513
    HY=H2*(1.+ZZW)                                                 118513
    HZR=H3*(1.+ZZR)                                                118513
    HZF=H4*(1.+ZZF)                                                118513
    QUU=QSUN(N)*DZ/CG                                              118510
    QS=CG(TA,ZN1,ZN2,ZN3,1.)+BS
    TA1=TA+1.
    CS1=CG(TA1,ZN1,ZN2,ZN3,1.)+BS
    Y1=CS1-CS
    Y2=CS*TA1-CS1*TA
    CL=CG(TA,ZN1,ZN2,ZN3,0.)+BL
    WV=W(DPV(N))
    RX=RO-2.*EX*HX
    RY=RO-2.*EY*HY
    RZR=RO-2.*EZ*HZR
    RZF=RO-2.*EZ*HZF
702 IF(L3)231,231,845
845 IF(K-NN) 245,231,231
231 PRINT 232                                                      118511
232 FORMAT(50H1  EARTH TEMPERATURE ON   Z-X PLANE  AT J=1         )118511
    DO  235  K=1,IZ3                                               118511
235 PRINT 234,(T(I, 1,K),I=1,IX2)                                  118511
    PRINT 236                                                      118511
236 FORMAT(50H1  EARTH TEMPERATURE ON   Z-X PLANE  AT J=JJ        )118511
    DO  237  K=1,IZ3                                               118511
237 PRINT 234,(T(I,JJ,K),I=1,IX2)                                  118511
    PRINT 238                                                      118511
238 FORMAT(50H1  EARTH TEMPERATURE ON   Z-Y PLANE  AT I=1         )118511
    DO  239  K=1,IZ3                                               118511
239 PRINT 234,(T(1,J,K),J=1,IY2)                                   118511
    PRINT 240                                                      118511
240 FORMAT(50H1  EARTH TEMPERATURE ON   Z-Y PLANE  AT I=II        )118511
    DO  241   K=1,IZ3                                              118511
241 PRINT 234,(T(II,J,K), J=1, IY2)                                118511
    PRINT 242                                                      118511
242 FORMAT(50H1  EARTH TEMPERATURE ON   X-Y PLANE  AT  K=KK       )118511
    DO  243   J=1,IY2                                              118511
243 PRINT 234,(T(I,J,KK),I=1,IX2)                                  118511
C  EARTH TEMPERATURE BOUNDARIES                                    118511
245 DO   103    I=1,IX2                                            118511
    DO   103    J=1,IY2                                            118511
    IF(WG) 101,101,102                                             118511
101 T(I,J,1)=DB(N)                                                 118511
    GO TO 103                                                      118511
102 TG = 0.
802 T(I,J,1)=2.*EZ*(T(I,J,2)+HGU*DB(N)+QUU)*DTG/DT+T(I,J,1)*RG
    IF (TG-CF) 803,103,103
803 TG=TG+DTG
    GO TO 802
103 T(I,J,IZ3)=TGO(IZ3)                                            118511
    TGO(1)=T(IX2,IY2,1)
  UNDISTURBED EARTH TEMPERATURE
    DO   104    K=2,KZ                                             118511
104 TGO(K)=EZ*(TGO(K-1)+TGO(K+1))+TGO(K)*(1.-2.*EZ)                118511
    DO 105 K=2,KZ
    DO   105    J=1,IY2                                            118511
```

```
  105 T (IX2,J,K)=TGO(K)                                                     118511
      DC 106 K=2,KZ
      DO 106 I=1,IY2
  106 T(I,IY2,K)=TGO(K)
      DC  900     K=2,"?                                                     118511
      DO  900     J=1,KY                                                     118511
      DO  900     I=1,KX                                                     118511
      P2=T(I+1,J,K)                                                          118511
      P4=T(I,J+1,K)                                                          118511
      P5=T(I,J,K-1)                                                          118511
      P6=T(I,J,K+1)                                                          118511
      IF(I-1) 1,1,2                                                          118511
    1 P1=P2                                                                  118511
      GO TO 3                                                                118511
    2 P1=T(I-1,J,K)                                                          118511
    3 IF(J-1) 4,4,5                                                          118511
    4 P3=P4                                                                  118511
      GC TO 6                                                                118511
    5 P3=T(I,J-1,K)                                                          118511
    6 PO=T(I,J,K)                                                            118511
C  END OF  PREPARATION                                                       118511
      IF(I-IX1) 7,11,11                                                      118511
    7 IF(J-IY1) 8,11,11                                                      118511
    8 IF(IZ1-K) 9,11,11                                                      118511
    9 IF(K-IZ2)10,11,11                                                      118511
   10 GC TO 900                                                              118511
   11 IF(K-IZ1)800,12,19                                                     118511
   12 IF(I-IX1) 13,15,800                                                    118511
   13 IF(J-IY1) 14,18,800                                                    118511
   14 PO=EX*(P1+P2)+EY*(P3+P4)+2.*EZ*(P5+HZR*PR)+PO*RZR                      11851?
      GO TO 900                                                              11851?
   15 IF(J-IY1) 16,17,800                                                    118511
   16 PO=(EX/3.)*(2.*P1+4.*P2)+EY*(P3+P4)+(EZ/3.)*(4.*P5+2.*P6)+PO*RO        118511
      GO TO 900                                                              118511
   17 PO=(EX/7.)*(6.*P1+8.*P2)+(EY/7.)*(6.*P3+8.*P4)+(EZ/7.)*(8.*P5+6.*P118511
     16)+PO*RO                                                               118511
      GO TO 900                                                              118511
   18 PO=EX*(P1+P2)+(EY/3.)*(2.*P3+4.*P4)+(EZ/3.)*(4.*P5+2.*P6)+PO*RO        118511
      GO TO 900                                                              118511
   19 IF(IZ2-K) 800,26,20
   20 IF(I-IX1) 24,21,  800                                                  118511
   21 IF(J-IY1) 22,23,  800                                                  118511
   22 PO=EY*(P3+P4)+EZ*(P5+P6)+2.*EX*(P2+HX *PW)+PO*RX                       118513
      GO TO 900                                                              118511
   23 PO=(EX/3.)*(2.*P1+4.*P2)+(EY/3.)*(2.*P3+4.*P4)+EZ*(P5+P6)+PO*RO        118511
      GO TO 900                                                              118511
   24 IF(J-IY1)900,25,  800                                                  118511
   25 PO=EX*(P1+P2)+EZ*(P5+P6)+2.*EY*(P4+HY *PW)+PO*RY                       118513
      GO TO 900                                                              118511
   26 IF(I-IX1) 27,30,800                                                    118511
   27 IF(J-IY1) 28,29,800                                                    118511
   28 PO=EX*(P1+P2)+EY*(P3+P4)+2.*EZ*(P6+HZF*PF)+PO*RZF                      118513
      GO TO 900                                                              118511
   29 PO=EX*(P1+P2)+(EY/3.)*(2.*P3+4.*P4)+(EZ/3.)*(2.*P5+4.*P6)+PO*RO        118511
      GC TO 900                                                              118511
   30 IF(J-IY1) 31,32,800                                                    118511
   31 PO=(EX/3.)*(2.*P1+4.*P2)+EY*(P3+P4)+(EZ/3.)*(2.*P5+4.*P6)+PO*RO        118511
      GO TO 900                                                              118511
   32 PO=(EX/7.)*(6.*P1+8.*P2)+(EY/7.)*(6.*P3+8.*P4)+(EZ/7.)*(8.*P6+6.*P118511
     15)+PO*RO                                                               118511
```

```
      GC TO 900                                                    118511
  800 PC=EX*(P1+P2)+EY*(P3+P4)+EZ*(P5+P6)+PO*RO                    118511
  900 T(I,J,K)=PO
  910 ZT=0.                                                        11851
      ZN=0.                                                        11851
      DC  911     K=IZ1,IZ2                                        11851
      DC  911     J=1,IY1                                          11851
      ZT=ZT+T(IX1,J,K)                                             11851
  911 ZN=ZN+1.                                                     11851
      TSX=ZT/ZN                                                    11851
      ZT=0.                                                        11851
      ZN=0.                                                        11851
      DO  912     K=IZ1,IZ2                                        11851
      DC  912     I=1,IX1                                          11851
      ZT=ZT+T(I,IY1,K)                                             11851
  912 ZN=ZN+1.                                                     11851
      TSY=ZT/ZN                                                    11851
      ZN=0.                                                        11851
      ZT=0.                                                        11851
      DO    913   I=1,IX1                                          11851
      DO    913   J=1,IY1                                          11851
      ZT=ZT+T(I,J,IZ1)                                             11851
  913 ZN=ZN+1.                                                     11851
      TSZR=ZT/ZN                                                   11851
      ZN=0.                                                        11851
      ZT=0.                                                        11851
      DO    914   I=1,IX1                                          11851
      DO    914   J=1,IY1                                          11851
      ZT=ZT+T(I,J,IZ2)                                             11851
  914 ZN=ZN+1.                                                     11851
      TSZF=ZT/ZN                                                   11851
      QX=HW*( .+ZZW)*(PW-TSX)                                      118513
      QY=HW*(1.+ZZW)*(PW-TSY)                                      118513
      QZR=HR*(1.+ZZR)*(PR-TSZR)                                    118513
      QZF=HF*(1.+ZZF)*(PF-TSZF)                                    110513
      TSW=(TSX*SX+TSY*SY)/(SX+SY)                                  118513
      TSF= SZF                                                     118513
      TSR=TSZR                                                     118513
      TSM=(TSW*SW+TSR*SR+TSF*SF)/(SW+SR+SF)                        118513
      TA=(1.08*CFM*TV(N)+Y2+HW*TSW*SW+HR*TSR*SR+HF*YSF*SF)/(1.08*CFM-Y1+118513
     1HW*SW+HR*SR+HF*SF)                                           118513
      QL=CG(TA,ZN1,ZN2,ZN3,0.)+BL                                  118513
      WW=W(TSW)                                                    118513
      WR=W(TSR)                                                    118513
      WF=W(TSF)                                                    118513
      HW=HW/ZLW
      HR=HR/ZLR
      HF=HF/ZLF
      WA=(4780.*CFM*WV+QL+(1061.)*(WW*SW*HW+WR*SR*HR+WF*SF*HF)/0.243)/(4118513
     1780.*CFM+(1061.)*(SW*HW+SR*HR+SF*HF)/C.243)                  118513
      HW=HW*ZLW
      HR=HR*ZLR
      HF=HF*ZLF
      WS=W(TSM)                                                    118513
      IF(WA-WS) 610,610,611                                        118513
  610 WA=(4780.*CFM*WV+QL)/(4780.*CFM)                             118513
  611 PSA = WA*PB/(WA+0.622)                                       118513
      RHA(N)=100.*PSA/GN(TA)
  613 FORMAT(5F10.2)                                               118513
      PRINT613,QX,QY,QZR,QZF,TM                                    118513
```

```
      STM(N)=TSM
      ST1(N)=TSX
      ST2(N)=TSY
      ST3(N)=TSZR
      ST4(N)=TSZF
      V(N)=TM
      Y(N)=TM
  907 TAA(N)=TA
      PRINT 950
  950 FORMAT(100H1          TM          STM          ST1          ST2          ST3
     1  ST4          RHA          TAA                                        )
      DO 951  N=1,NN
  951 PRINT  954,Y(N),STM(N),ST1(N),ST2(N),ST3(N),ST4(N),RHA(N),TAA(N)
  954 FORMAT(8F10.2)
      EB(1)=0.
      EB(2)=500.
      EC(1)=100.
      EC(2)=40.
      CALL PLOT(3,NN,Y,STM,NN,V,TAA,2,EB,EC)
  901 CONTINUE                                                          118512
      CALL SYSTEM                                                       118512
      GO TO 199                                                         118512
      END
```

Program M-4 Input and Output Symbols

NN: Total number of time iterations.

II: Number of ventilation air inlets where temperatures were observed.

JJ: Number of shelter air temperature stations.

KK: Total number of shelter inner surface temperature stations.

KWC: If ≤0, Ft. Belvoir 1000-man shelter analysis.

If >0, Ft. Belvoir 200-man shelter analysis.

WC: If ≤0, constant earth temperature, TGø, is read in.

If >0, six directional earth temperature profiles, TG(I,M), will be read in.

AI: If >0, air conditioning calculations are included.

WC1: If ≤0, cfm varies with time.

WC2: If ≤0, number of occupants varies with time.

TGø: Constant initial earth temperature, °F.

TG(I,M): Six directional initial earth temperature profiles, °F.

TCø(M): Initial inner wall temperatures, °F.

TC(L,M): Initial temperature profile within the shelter inner walls, °F.

S(K): Shelter inner surface area, ft^2.

DD(K): Finite difference length for inner wall, ft.

DC(K): Finite difference length for earth region, ft.

D(K): Thickness of the inner wall, ft.

ZL(K): Thickness of the earth block, ft.

AG(K): Thermal diffusivity of earth, ft^2/hr.

AC(K): Thermal diffusivity of inner wall, ft^2/hr.

CK(K): Thermal conductivity of inner wall, Btu/hr ft, °F.

CG(K): Thermal conductivity of earth block, Btu/hr, ft, °F.

H(K): Heat transfer coefficient of the inner surface, Btu/hr, ft^2, °F.

HD(K): Vapor transfer coefficient of the inner surface, lb/hr, ft^2 (lb/lb).

DT: Finite difference time for inner wall temperature calculation, hr.

DTT: Finite difference times for earth temperature calculation, hr.

GS: Per capita sensible heat generation from non-human heat source, Btu/hr, person.

GL: Per capita latent heat generation from non-human heat source, Btu/hr, person.

GA: Recirculation air rate for conditioning, cu ft/min.

FR: Coil effectiveness of the air conditioner (dimensionless).

CF: Coil contact factor of the air conditioner (dimensionless).

DATT: Coil leaving air temperature rise due to fan heat, °F.

TW1: Entering temperature of the coolant to the air conditioner coil, °F.

XDB(N): Outdoor air dry-bulb temperature, °F.

TV(N): Ventilation air dry-bulb temperature, °F.

DPV(N): Ventilation air dew-point temperature, °F.

EG(K): Finite difference stability modulus for earth temperature calculation, which should not exceed 0.5.

E(K): Finite difference stability modulus for shelter inner-wall temperature calculation, which should not exceed 0.5.

EC(K): E(K).

TM: Elapsed time (hr).

QVS: Sensible heat carried out by ventilation air, Btu/hr.

QVL: Latent heat carried out by ventilation air, Btu/hr.

QGS: Sensible heat generated in the shelter, Btu/hr.

QGL: Latent heat generated in the shelter.

QWST: Sensible heat absorbed by shelter surface, Btu/hr.

QWLT: Latent heat absorbed by shelter surface, Btu/hr.

TWCT: Condensate collected in the shelter, lb/hr.

QAS: Sensible heat absorbed by the air conditioner, Btu/hr.

QAL: Latent heat absorbed by the air conditioner, Btu/hr.

TA: Shelter air dry-bulb temperature, °F.

DPA: Shelter air dew-point temperature, °F.

WBA: Shelter air wet-bulb temperature, °F.

RHA: Shelter air relative humidity, %.

EFS1: Shelter air effective temperature, °F.

TSM: Average shelter inner surface temperature, °F.

QWS(K): Sensible heat transferred to the Kth surface, Btu/hr.

QWL(K): Latent heat transferred to the Kth surface, Btu/hr.

TWC(K): Condensate collected onto the Kth surface, lb/hr.

FLX(K): Heat flux of the Kth surface, Btu/hr, ft^2.

TS(K): Average temperature of the Kth surface, °F.

TC(L,K): Temperature distribution in the Kth inner wall, °F.

TG(I,K): Temperature distribution in the Kth block of the earth.

TIME(N): Elapsed time for the observed date, hr.

CFM(N): Ventilation air rate used in the experiment (time dependent), cfm.

ZN(N): Number of occupants used in the experiments (time dependent).

X1:   = DBV(N) - Observed ventilation air dry-bulb temperature, °F.

X2:   = WBV(N) - Observed ventilation air wet-bulb temperature, °F.

DBS: Observed shelter dry-bulb temperature.

WBS: Observed shelter wet-bulb temperature.

ETS1:   Shelter effective temperature based upon DBS and WBS.

Subscripts:

MwK = Type of wall exposure.

1. North wall
2. South wall
3. East wall
4. West wall
5. Floor
6. Roof

N = Time

L = Spatial matrix index for inner wall

I = Spatial matrix index for earth region

Subroutines:

(1) FREP: This subroutine is designed to accept observed data of prototype shelter and yield the psychrometrically processed mean shelter conditions in terms of temperature, humidity and heat flux. Following are the input data specific to this subroutine.

KWS: The first temperature entry for XWS table.

NWS: The total number of temperature entries for XWS table.

XWS(I):   Saturated air humidity ratio table of Goff and Gratch, lb/lb.

KHA: The first temperature entry for XHA table.

NHA: The total number of temperature entries for XHA table.

XHA(I): Dry air enthalpy table of Goff and Gratch, Btu/lb.

KHS: The first temperature entry for moisture XHS table, °F.

NHS: The total number of temperature entries for XHS table.

XHS(I): Moisture saturated air enthalpy table of Goff and Gratch, Btu/lb.

KFS: The first temperature entry for the XFS table.

NFS: The total number of temperature entries for XFS table.

XFS(I): Factors relating the degree of saturation to the relative humidity.

KHW: The first temperature entry for the XHW table.

NHW: The total number of temperature entries for XHW table.

XHW(I): Liquid water enthalpy table of Goff and Gratch, Btu/lb.

KVA: The first temperature entry for the XVA table.

NVA: The total number of temperature entries for XVA table.

XVA(I): Dry air volume table of Goff and Gratch, cu ft/lb.

KVS: The first temperature entry for the XVS table.

NVS: The total number of temperature entries for XVS table.

XVS(I): Moisture saturated air volume table of Goff and Gratch, cu ft/lb.

KQS: The first temperature entry for the XQS table.

NQS: The total number of temperature entries for XQS table.

XQS(I): Per capita sensible heat table of human body, Btu/hr.

EDB(I): Dry-bulb temperature entries to ASHRAE effective temperature table, °F.

EWB(I): Wet-bulb temperature entries to ASHRAE effective temperature table, °F.

(2) STRCON: Subroutine to compute adiabatic shelter air conditions by accepting ventilation air dry- and wet-bulb temperatures and ventilation air flow rate.

(3) AIRCØN: Subroutine to compute sensible and latent heat absorption by accepting the following input data.

GA:	Recirculation air rate, cfm.
CFM:	Ventilation air rate, cfm.
DBS:	Shelter air dry-bulb temperature, °F.
WBS:	Shelter air wet-bulb temperature, °F.
DBV:	Ventilation air dry-bulb temperature, °F.
WBV:	Ventilation air wet-bulb temperature, °F.
TW1:	Inlet temperature of the air conditioner coolant, °F.
E:	Effectiveness of the air cooling coil.
CF:	Contact factor of the air cooling coil.
DTA:	Dry-bulb temperature rise of the air conditioner outlet air due to the fan heat, °F.

(4) FN: Boundary temperature calculation subroutine by a finite difference formula.

(5) EFTI: Subroutine for computing effective temperature by using the input data of dry- and wet-bulb temperatures.

(6) DBWBH: Subroutine for computing enthalpy of moist air using dry- and wet-bulb temperatures.

(7) DBWBRH: Subroutine for calculating relative humidity for given dry- and wet-bulb temperatures and barometric pressure, PB (in. Hg).

(8) DBWWBH: Subroutine to calculate wet-bulb temperatures and enthalpy of moist air based upon given values of the dry-bulb temperature and humidity ratio.

(9) PV: Subroutine for calculating the vapor pressure in inches of Hg of saturated moist air at given temperatures.

(10) DBWBDP: Subroutine for calculating the dew-point temperature and humidity ratio of moist air for given dry- and wet-bulb temperatures.

(11) DBWPWB: Subroutine for calculating the wet-bulb temperature and humidity ratio when dry-bulb temperatures and dew-point temperatures are given.

(12) TBLU: Table look-up and linear interpolation subroutine when the independent variable is incremented by unity.

(13) XTBLU: Table look-up and linear interpretation subroutine when the incrementation of the independent variable is non-unity.

```
C  ONE DIMENSIONAL SHELTER                                                 11851003
C    SUBROUTINE TO BE USED IN THE PROGRAM                                  11851004
C     PREP(DT,II,JJ,KK,KWC,NN)                                             11851M03
C      STRCON(DB,WB,G)     ADIABATIC SHELTER AIR CONDITION CALCULATION
C                   AIRCON(GA,CFM,DBS,WBS,DBV,WBV,TWI,E,CF, QAS,QAL,DTA)  11851A02
C     FUNCTION    FN
C     EFT1(DB,WB,EFX)
C    DBWBH(DB,WB,H)           GIVEN  DB AND WB ,COMPUTE H                 11851012
C    DBWBRH(DB,WB,PB,RH)      GIVEN  DB,WB,PB  ,COMPUTE RH                11851014
C    DBWWBH(DB,W,WB,H)        GIVEN  DB AND W  ,COMPUTE WB AND H          11851011
C    FUNCTION  PV(X,PB)       CALCULATE VAPOR PRESSURE FOR GIVEN DB AND PB11851018
C    DBWBDP(DB,WB,DP,W)       GIVEN  DB AND WB ,COMPUTE DP AND W          11851010
C    DBDPWB(DB,DP,WB, W)      GIVEN  DB AND DP, COMPUTE WB                11851013
C    TBLU (X,KX,V,Y)          KX=FIRST VARIABLE                           11851015
C                              V=TABLE                                    11851016
C                             Y=VALUE FOR X                               11851017
C    XTBLU(X,DX,KX,LX,V,Y), DX=VARIABLE  INCREMENT                        11851005
C                             KX=FIRST VARIABLE                           11851006
C                             LX=NUMBEROF ENTRIES                         11851007
C                             V =TABLE                                    11851008
C                             Y =VALUE OBTAINED FOR X                     11851009
C  1=NORTH,2=SOUTH,3=EAST,4=WEST,5=FLOOR,6=ROOF,J=ROOF MATRIX             11851008
C     AI=0 -  NO AIR CONDITIOING,  +=AIR CONDITIONING
C     WC=O-, CONSTANT           TGO  ,+=PROFILE                           11851M12
C     II =NUMBER OF  VENTILATION  TEMP. DATA                              11851004
C     JJ =NUMBER OF  SHELTER      TEMP. DATA                              11851005
C     KK =NUMBER OF  WALL         TEMP. DATA                              11851006
C    KWC  =+  200MAN  INPUT  ,0- =1000 MAN  INPUT                         11851007
C     WC1=- OR 0    CFM   VARIES
C     WC2=- OR 0  ZN  VARIES
C  DT=   FIRST ESTIMATE OF CONCRETE TIME
C   DTT=   EARTH TIME
      DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),XVA(150),XV11851M04
     1S(150),QS(50),CFM(300),ZN(300),
     2DBV(300),DPV(300),WBV(300),DBC(3,300),WBC(2,300),PS(10,300),
     3TV(300),DPC(300),LA(300,10),LB(300,10),XDB(300),EDB(100),EWB(100),
     4ET(50,50), TWC(6),EC(6),EG(6),TS(6),TSS(6)
     5       , TG(10,6),TC(5,6),S(6),D(6),DD(6),ZL(6),DG(6),AG(6),AC(6)11851004
     6,CK(6),CG(6),H(6),HD(6),       QWS(6),QWL(6),TQWS(6),TQWL(6),TQW(6)11851005
     7, DX(6),CS(6),QW(6),FLX(6),E(6) ,AS(6),ES(6),TCO(6),TIME(300)
      COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS,EDB,EWB,ET,    KET,N11851M09
     1ET,QS,CO1,CO2,UO,TW,GS,GL,ZLEWS,CFM,DPS,DBS,WBS,ETS1,ETS2,WCC,CO3,11851M10
     2WCD,DPA,ZN,QG,QGL,DBV,DPV,DBC,DPC,WBC, S,TA,DT,KWC,NN,XVA,
     3XVS,XVA,KVS,PS,LA,LB,XDB,WBV,WC1,WC2    ,DTT
   77 FORMAT(1H010F10.1)
    1 FORMAT(10F7.0)                                                       11851009
    2 FORMAT(10I7)                                                         11851010
   12 FORMAT(43H1      UNDERGROUND  FALLOUT  SHELTER  DATA         )       11851057
   13 FORMAT(43H0      INITIAL  EARTH  TEMPERATURES                )       11851058
   14 FORMAT(43H0      INITIAL  CONCRETE WALL  TEMPERATURE         )       11851059
   15 FORMAT(43H1      TIME  VARIABLES                             )       11851060
   16 FORMAT(43H0    DB(N)     TV(N)     DPV(N)    QSUN(N)         )       11851061
   17 FORMAT(4F10.1)                                                       11851062
   18 FORMAT(63H     TG(1)      TG(2)      TG(3)      TG(4)      TG(5)     TG11851063
     1(6)                                                                 )11851064
   19 FORMAT(63H     TC(1)      TC(2)      TC(3)      TC(4)      TC(5)     TC11851065
     1(6)                                                                 )11851066
   20 FORMAT(6F10.1)                                                       11851067
  124 FORMAT(43H1      PHYSICAL DATA USED FOR COMPUTATION          )       11851081
  125 FORMAT(110HOS(K)       D(K)       ZL(K)      CK(K)      CG(K)     AC(K11851082
```

```
   1)    AG(K)      H(K)       HD(K)                                          )11851083
 126 FORMAT(10F10.4)                                                           11851084
  64 FORMAT(16H0 QWS(M)              6F15.1)                                   11851206
  65 FORMAT(16H0 QWL(M)              6F15.1)                                   11851207
   6 FORMAT(16H0 TWC(M)              6F15.1)                                   11851208
  67 FORMAT(16H0 FLX(M)              6F15.1)                                   11851209
  68 FORMAT(16H0 TS(M)               6F15.1)                                   11851210
  69 FORMAT(14H CONC.TEMP.    1I1,   6F15.1)                                   11851211
  74 FORMAT(14H EARTH TEMP    1I1,   6F15.1)                                   11851212
  63 FORMAT(120H- EXPOSURES                    1              2
   1    3            4              5              6               )
 203 FORMAT(100H0                 EG(1)         EG(2)           EG(3)
   1        EG(4)         EG(5)                                    )
 205 FORMAT(100H0                EC(1)          EC(2)           EC(3)
   1         EC(4)         EC(5)          EC(6)                    )
 204 FORMAT(10H                     6F15.3)
 210 FORMAT(50H0        DBV        DPV        WBV      CFM                    )11851M50
  75 FORMAT(10F10.2)
  76 FORMAT(60H0        DBS        DPS        WBS        RHS        ET
   2  TS                                              )
7100 FORMAT(10H-                        )
  62 FORMAT(10F10.0)                                                           11851202
 211 FORMAT(3F15.1)
 158 FORMAT(50H-  OBSERVED   SHELTER   CONDITION                              )11851M53
 159 FORMAT(50H-  CALCULATED SHELTER   CONDITION                              )11851M55
5000 FORMAT(72H1
   1                                                              )
  61 FORMAT(100H1      TIME       QVS       QVL       QGS       QGL
   2 QWST     QWLT      TWCT       QAS       QAL                           )
6000 FORMAT(50H1   ADIABATIC   SHELTER  RESULTS                             )
7000 FORMAT(90H0       TIME        CFM         ZN        DBV        WBV
   1 DBS       WBS       EFT                        )
7001 FORMAT(10F10.1)
8999 FORMAT(10F12.2)
     READ 5000
     PRINT 5000

     READ 2,NN
     READ 2,II,JJ,KK,KWC                                                       11851M33
  59 READ 1,WC    ,AI  ,WC1,WC2
     PRINT 158
     IF(WC) 3,3,4                                                              11851013
   3 READ 1,TG0                                                                11851M35
     DO 5   M=1,5                                                              11851015
     DO 5   I=1,10                                                             11851016
   5 TG(I,M)=TG0                                                               11851017
     GO TO 7                                                                   11851M38
   4 DO  1000   M=1,5                                                          11851M36
1000 READ1,(TG(I,M),I=1,10)                                                    11851M37
   7 READ1,(TCO(M),M=1,6)                                                      11851M39
     DO 8    L=1,5                                                             11851M40
     DO 8  M=1,6
   8 TC(L,M)=TCO(M)                                                            11851M41
  11 READ 1,(S(K),K=1,6)                                                       11851043
     READ 1,(DD(K),K=1,6)                                                      11851044
     READ 1,(DG(K),K=1,6)                                                      11851045
     READ 1,(D(K),K=1,6)                                                       11851046
     READ 1,(ZL(K),K=1,6)                                                      11851047
     READ 1,(AG(K),K=1,6)                                                      11851048
     READ 1,(AC(K),K=1,6)                                                      11851049
```

```
      READ 1,(CK(K),K=1,6)                                              11851050
      READ 1,(CG(K),K=1,6)                                              11851051
      READ 1,(H(K),K=1,6)                                               11851052
      READ 1,(HD(K),K=1,6)                                              11851053
      PB=29.97
      READ 1,DT,DTT,GS,GL
      CO1=1.08
      CO2=4.5
      CO3=1050.
      UO=0.
      TW=70.
      ZLENS=1.
      WCC=-1.0
      WCD=-1.0
      CALL PREP
      TIME(1)=0.                                                        11851M15
      DO 9 N=1,NN
      TV(N)=DBV(N)
    9 TIME(N)=TIME(N-1)+DTT                                             11851M31
      IF(AI) 5005,5005,5006
 5006 READ 1, GA,ER,CF,DATT,TW1
 5005 CONTINUE
      PRINT 12                                                          11851068
      PRINT 13                                                          11851069
      PRINT 18                                                          11851070
      DO  21 I=1,10                                                     11851071
   21 PRINT 20,(TG(I,M),M=1,5)
      PRINT 14                                                          11851073
      PRINT 19                                                          11851074
      DO  22       L=1,5                                                11851075
   22 PRINT 20, (TC(L,M),M=1,6)                                         11851076
      PRINT 15                                                          11851077
      PRINT 16                                                          11851078
      DO 5015 N=1,NN
 5015 PRINT 20,XDB(N),TV(N),DPV(N)
      PRINT124                                                          11851085
      PRINT125                                                          11851086
      DO127  K=1,6                                                      11851087
  127 PRINT126,S(K),D(K),ZL(K),CK(K),CG(K),AC(K),AG(K),H(K),HD(K)
   26 DO  28  K=1,6                                                     11851097
      DX(K)=DD(K)                                                       11851100
      AS(K)=AC(K)
   28 CS(K)=CK(K)                                                       11851101
      DST=DT                                                            11851102
      DO 801     K=1,6
  801 E(K)=AC(K)*DT/(DD(K)*DD(K))                                       11851176
      DO 802 K=1,5
  802 EG(K)=AG(K)*DTT/(DG(K)*DG(K))                                     11851184
      ECMAX=E(1)                                                        11851M16
      JK=1
      DO  58   K=2,6                                                    11851M17
      IF(E(K)-ECMAX) 58,58,59                                           11851M18
   59 ECMAX=E(K)
      JK=K                                                              11851M20
   58 CONTINUE                                                          11851M21
      IF(ECMAX-0.5) 91,91,92                                            11851M22
   92 DST=0.4*DD(JK)*DD(JK)/AC(JK)                                      11851M23
      DO  93  K=1,6                                                     11851M24
   93 E(K)=AC(K)*DST/(DD(K)*DD(K))
   91 CONTINUE                                                          11851M26
```

```
      PRINT 203
      PRINT 204,(EG(K),K=1,5)
      PRINT 205
      PRINT 204,(E(K),K=1,6)
      TM=0.
      DO 202   K=1,6
  201 TSS(K)=TC(2,K)
  202 TS(K)=TC(1,K)
      DO 800 N=1,NN                                             11851105
      TM=TM+DTT
      X1=DBV(N)
      X2=WBV(N)
      G=CFM(N)
      ZP=DPV(N)
      PSV=PV(ZP,PB)                                             11851107
      WV=0.622*PSV/(PB-PSV)


      DTM=0.                                                    11851108
   53 DTM=DTM+DST                                               11851111
      IR=1                                                      11851109
      DTA=1.0
      TA1=TA-20.                                                11851112
   30 QVS=1.08*G*(TA1-TV(N))


      CALL XTBLU(TA1,5.,60,9,QS,QGP)
      QGS=(QGP+GS)*ZN(N)
      IF(KTEST)6995,6995,6994
 6994 CONTINUE
      PRINT 8999,QGP,QGS
 6995 CONTINUE
      CALL DBDPWB(TA1,DPA,WBA,WT)
      IF(AI) 5007,5007,5008
 5008 CALL AIRCON(GA,G,TA1,WBA,X1,X2,TW1,ER,CF,QAS,QAL,DTAA)
      GO TO 5009
 5007 QAS=0.
      QAL=0.
 5009 CONTINUE


                                                                11851114
      QWST=0.                                                   11851115
      DO  31   K=1,6                                            11851116
      QWS(K) =H(K)*S(K)*(TA1-TS(K))                             11851117
   31 QWST= QWST +QWS(K)


                                                                11851118
      GO TO (32,36),IR
   32 ZX=QGS-QVS-QWST-QAS
```

```
                                                                  11851120
      IF(ZX) 34,35,33                                             11851121
   33 TA1=TA1+DTA                                                 11851122
      ZX2=ABSF(ZX)                                                11851123
      GO TO 30                                                    11851124
   34 TA2=TA1-DTA                                                 11851125
      ZX1=ABSF(ZX)                                                11851126
      TA=(TA1*ZX2+TA2*ZX1)/(ZX1+ZX2)                              11851127
      IR=2                                                        11851128
      TA1=TA                                                      11851129
      GO TO  30                                                   11851130
   35 TA= TA1                                                     11851131
   36 DDPA=0.2
      DPA1=DPA-10.                                                11851133
      IR=1
   37 PSA=PV(DPA1,PB)


                                                                  11851135
      WA=0.622*PSA/(PB-PSA)                                       11851136
      QVL=4780.*G*(WA-WV)
      CALL DBDPWB(TA,DPA1,WBA,WT)
      IF(AI) 5010,5010,5011
 5011 CALL AIRCON(GA,G,TA ,WBA,X1,X2,TW1,ER,CF,QAS,QAL,DTAA)
      GO TO 5012
 5010 QAS=0.
      QAL=0.
 5012 CONTINUE                                                    11851137
      QWLT=0.                                                     11851138
      TWCT=0.                                                     11851139
      DO  42    K=1,6
      PSW=PV(TS(K),PB)                                            11851141
      WS=0.622*PSW/(PB-PSW)                                       11851142
      ZP=WA-WS                                                    11851143
      IF(ZP) 39,39,40                                             11851144
   39 QWL(K)=0.                                                   11851145
      GO TO 41                                                    11851146
   40 QWL(K)=1061.*HD(K)*S(K)*ZP                                  11851147
   41 QWLT=QWLT+QWL(K)                                            11851148
      TWC(K)=QWL(K)/1061.                                         11851149
   42 TWCT=TWCT+TWC(K)
      CALL XTBLU(TA,5.,60,9,QS,QGP)
      QGL=(400.-QGP+GL)*ZN(N)


                                                                  11851151
      GO TO (43,47),IR
   43 ZY=QGL-QVL-QWLT-QAL                                         11851153
      IF(ZY) 45, 46,44                                            11851154
   44 DPA1=DPA1+DDPA                                              11851155
      ZY2=ABSF(ZY)                                                11851156
      GO TO  37                                                   11851157
   45 DPA2=DPA1-DDPA                                              11851158
      ZY1=ABSF(ZY)                                                11851159
      DPA=(DPA1*ZY2+DPA2*ZY1)/(ZY1+ZY2)                           11851160
      IR=2                                                        11851161
      DPA1=DPA                                                    11851162
      GO TO 37
```

```
      WB=WBA
      CALL EFT1(DB,WB,EFS1)


      DO  50   K=1,6                                                    11851166
      FLX(K)=(QWS(K)+QWL(K))/S(K)                                       11851167
      ES(K)=AS(K)*DST/(DX(K)*DX(K))
      TS(K)=2.*ES(K)*(FLX(K)*DX(K)/CS(K)+TSS(K)+TS(K)*(0.5*1./ES(K)-1.))
   49 TC(1,K)=TS(K)                                                     11851172
   50 CONTINUE                                                          11851173
      IF(KTEST) 6985,6985,6984
 6984 CONTINUE
      PRINT 8999,(TS(K),K=1,6)
 6985 CONTINUE
   51 DO 52 L=2,4
      DO 52 K=1,6
   52 TC(L,K)=E(K)*(TC(L-1,K)+TC(L+1,K)+(1./E(K)-2.)*TC(L,K))           11851178
      DO 8002 K=1,6
 8002 TSS(K)=TC(2,K)


      IF(DTM-DTT) 53,54,54                                              11851179
   54 DO   55   K=1,5                                                   11851180
      TG(1,K)=FN(CK(K),CG(K),TC(4,K),TG(2,K),DD(K),DG(K),0.)            11851181
   55 TC(5,K)=TG(1,K)                                                   11851182
      TG(1,6)=TC(4,6)                                                   11851M46
      TC(5,6)=TG(1,6)                                                   11851M47
   56 DO 57  I=2,9
      DO 57 K=1,5
   57 TG(I,K)=EG(K)*(TG(I-1,K)+TG(I+1,K)+(1./EG(K)-2.)*TG(I,K))         11851186
   60 PRINT 61                                                          11851198
      TSM=0.
      DO 8001 K=1,6
 8001 TSM=TSM+TS(K)
      TSM=TSM/6.
      PRINT 62    ,TM,QVS,QVL,QGS,QGL,QWST,QWLT,TWCT ,QAS,QAL
      PRINT 159
      PRINT 76
      PRINT 75,TA,DPA,WBA,RHA,EFS1,TSM                                  11851M49
      PRINT 63                                                          11851203
      PRINT 64,(QWS(K),K=1,6)                                           11851213
      PRINT 65,(QWL(K),K=1,6)                                           11851214
      PRINT 66,(TWC(K),K=1,6)                                           11851215
      PRINT 67,(FLX(K),K=1,6)                                           11851216
      PRINT 68,(TS(K) ,K=1,6)                                           11851217
      PRINT 7100
   71 DO  70  L=2,5                                                     11851219
   70 PRINT 69, L,(TC(L,K),K=1,6)                                       11851220
      PRINT 7100
   72 DO  73  I=1,10                                                    11851221
```

```
                                                              11851222
   73 PRINT 74,I,(TG(I,K),K=1,5)
      PRINT 210
      PRINT 75,TV(N),DPV(N),WBV(N),CFM(N)                     11851223
  800 CONTINUE
      PRINT 6000
      PRINT 7000
      DO 8000  N=1,NN
      X1=DBV(N)
      X2=WBV(N)
      GM=CFM(N)
      CALL SYRCON(X1,X2,GM)
 8000 PRINT 7001, TIME(N),CFM(N),ZN(N),X1,X2,DBS,WBS,ETS1     11851224
      CALL SYSTEM
      END
```

```
      SUBROUTINE    PREP
      DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),XVA(150),XV
     1S(150),QS(50),CFM(300),ZN(300),
     2DBV(300),DPV(300),DBC(3,300),DPC(300),PS(10,300)
     3       ,LA(300,10),LB(300,10),XDB(300),WBV(300),EDB(100),EWB(100
     4),ET(50,50),WBC(2,300),S(6)
      COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS,EDB,EWB,ET,    KET,N11851MC9
     1ET,QS,CO1,CO2,UO,TW,GS,GL,ZLEWS,CFM,DPS,DBS,WBS,ETS1,ETS2,WCC,CO3,11851M10
     2WCD,DPA,ZN,QG,QGL,DBV,DPV,DBC,DPC,WBC, S,TA,DT,KWC,NN,XVA,
     3XVS,KVA,KVS,PS,LA,LB,XDB,WBV,WC1,WC2    ,DTT
   26 FORMAT(120H0       TIME          DBV          WBV          DBS          WBS
     1    ET          QGT          QVT          QWT          QWS          TSM          HTX)
   50 FORMAT(10I7)                                                      11851002
   52 FORMAT(7F10.1)                                                    11851024
    1 FORMAT(10F7.0)                                                    11851011
    2 FORMAT(10I7)                                                      11851012
      READ 2,KWS,NWS                                                    11851015
      READ 1,(XWS(I),I=1,NWS)                                           11851016
      READ 2,KHA,NHA                                                    11851017
      READ 1,(XHA(I),I=1,NHA)                                           11851018
      READ 2,  KHS,NHS                                                  11851019
      READ 1,(XHS(I),I=1,NHS)                                           11851020
      READ 2,KFS,NFS                                                    11851021
      READ 1,(XFS(I),I=1,NFS)                                           11851022
      READ 2,KHW,NHW                                                    11851023
      READ 1,(XHW(I),I=1,NHW)                                           11851024
      READ 2,KVA,NVA                                                    11851025
      READ 1,(XVA(I),I=1,NVA)                                           11851026
      READ 2,KVS,NVS                                                    11851027
      READ 1,(XVS(I),I=1,NVS)                                           11851028
      READ 2,KQS,NQS                                                    11851029
      READ 1,(QS(I),I=1,NQS)                                            11851030
      READ 1,(EDB(I),I=1,29)
      READ 1,  (EWB(I),I=1,30)
      DO 73 I=1,29
   73 READ 1,(ET(I,J),J=1,30)                                           11851048
      IF(WC1) 4,4,5
    4 READ 1,(CFM(N),N=1,NN)
      GO TO 6
    5 READ 1,CFMO
      DO 7 N=1,NN
    7 CFM(N)=CFMO
    6 IF(WC2) 8,8,9
    8 READ 1,(ZN(N),N=1,NN)
      GO TO 10
    9 READ 1,ZNO
      DO 11 N=1,NN
   11 ZN(N)=ZNO
   10 CONTINUE
   28 FORMAT(12F10.2)
      TIME=0.                                                           11851018
      ST=S(1)+S(2)+S(3)+S(4)+S(5)+S(6)
      IF(KWC) 61,61, 62                                                 11851F05
   61 DO 300 N=1,NN
      [illegible] 50,(LA(N,L),L=1,10)
      READ 50,(LB(N,L),L=1,10)
      GO TO 500
   62 READ 1,(DBV(   N),N=1,240)                                        11851F09
      READ 1,(WBV(   N),N=1,240)                                        11851F10
      READ 1,(DBC(1,N),N=1,240)                                         11851F12
```

```
      READ 1,(WBC(1,N),N=1,240)                                         11851F13
      READ 1,(DBC(2,N),N=1,240)                                         11851F14
      READ 1,(WBC(2,N),N=1,240)                                         11851F15
      READ 1,(DBC(3,N),N=1,240)
      READ 1,(XDB(N),N=1,240)
      DO63 J=1,10                                                       11851F18
   63 READ 1,(PS(J,N),N=1,240                                           11851F19
      DO 600 N=1,240
  600 CFM(N)=CFM(N)/2.
  500 PRINT 26                                                          11851014
      DO 400 N=1,NN
      IF(KWC) 401,401,402
  401 DBV(N)=LA(N,1)/10
      X=DBV(N)
      WBV(N)=LA(N,2)/10
      Y=WBV(N)
      CALL DBWBDP(X,Y,Z,WQ)                                             11851010
      DPV(N)=Z
      X=(LA(N,3)+LA(N,5)+LA(N,7)+LA(N,9))/40                            11851012
      DBSM=X
      Y=(LA(N,4)+LA(N,6)+LA(N,8)+LA(N,10))/40                           11851014
      WBSM=Y
      CALL DBWBDP(X,Y,Z,WQ)                                             11851016
      DPSM=Z
      X=(LB(N,1)+LB(N,2)+LB(N,3)+LB(N,4)+LB(N,5)+LB(N,6)+LB(N,7)+LB(N,8)11851018
     1+LB(N,10))/90                                                     11851019
      IF(LB(N,4)) 53,53,54                                              11851020
   53 X=X*9./8.
   54 TSM=X
      XDB(N)=LB(N,9)/10
      GO TO  70                                                         11851F07
  402 X=DBV(N)
      Y=WBV(N)
      CALL DBWBDP(X,Y,Z,WD)                                             11851F23
      DPV(N)=Z
      X=(DBC(1,N)+DBC(2,N)+DBC(3,N))/3.
      DBSM=X
      Y=(WBC(1,N)+WBC(2,N))/2.
      WBSM=Y
      CALL DBWBDP(X,Y,Z,WD)                                             11851F27
      DPSM=Z
      SUM=0.                                                            11851F31
      SUN=0.                                                            11851F32
      DO  64    J=1,10                                                  11851F33
      IF(PS(J,N)) 64,64,66                                              11851F34
   66 SUM=SUM+PS(J,N)                                                   11851F35
      SUN=SUN+1.                                                        11851F36
   64 CONTINUE                                                          11851F37
   67 TSM=SUM/SUN
   70 CONTINUE                                                          11851F08
      DPC(N)=DPSM
      TIME=TIME+DTT
      X=DBV(N)
      Y=DPV(N)
      Z=WBV(N)
      CALL TBLU(X,KWS,XWS,WSS)                                          11851106
      CALL TBLU(Y,KWS,XWS,WSV)                                          11851107
      CALL TBLU(X,KVA,XVA,VA1)                                          11851108
      CALL TBLU(X,KVS,XVS,VS1)                                          11851109
      V=VA1+(VS1-VA1)*WSV/WSS                                           11851110
```

```
      XX=[illegible]M
      YY=[illegible]M
      ZZ=WBSM
      CALL FFTL(XX,ZZ,SET)
      CALL TRLU(YY,KWS,XWS,WSA)                                         11851024
      CALL XTBLU(XX,5.,60,9,QS,QGS)                                     11851113
      QGT=(400.+GS+GL)*ZN(N)                                            11851114
      QGS =QGS*ZN(N)
      WGL =(400.-QGS)*ZN(N)/1053.7                                      11851118
      QVS=CFM(N)/V*0.24*60.*(XX-X)                                      11851117
      WVL=CFM(N)/V*60.*(WSA-WSV)                                        11851115
      QVT=QVS+WVL*1054.                                                 11851116
      QWS=QGS-QVS-GS                                                    11851026
      QWT=QGT-QVT
      HTX=QWT/ST                                                        11851027
      RATIO=QWT/QGT
      PRINT 28,TIME,DBV(N),WBV(N),DBSM,WBSM,SET,QGT,QVT,QWT,QWS,TSM,    11851028
     1HTX
  400 CONTINUE
      TA=DBC(1,1)
      DPA=DPC(1)
      RETURN
      END                                                               11851029
```

```
C     SHELTER AIR CONDITION  CALCULATION                                 11851E02
      SUBROUTINE  STRCON(DB,WB,ZFM)
      DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),
     1EDB(100),EWB(100),ET(50,50),QS(50)   ,CFM(300)                     11851E05
      COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS,EDB,EWB,ET,
     3KET,NET,QS,CO1,CO2,UO,TW,GS,GL,ZLEWS,CFM,DPS,DBS,WBS,ETS1,ETS2    ,11851028
     4WCC,CO3,WCD
   12 FORMAT(10H     ETS1  F10.2)
   13 FORMAT(10H     ETS2  F10.2)
    9 FORMAT(10H     QGL   F10.2)
    4 FORMAT(10H     DBS   F10.2)
    5 FORMAT(10H     QGS   F10.2)
   14 FORMAT(10H      DPS  F10.2)
    6 FORMAT(10H     TWS   F10.2)
    7 FORMAT(10H      DP   F10.2)
   11 FORMAT(10H     WBS   F10.5)
   10 FORMAT(10H      WA   F10.5)
    8 FORMAT(10H      WV   F10.5)
      Y1=CO1*ZFM+UO
      Y2=CO1*ZFM*DB+UO*TW
      Y3=Y2/Y1
      IF(Y3-100.) 30,30,31                                               11851
   30 X1=Y3
    3 X2=X1+0.5
      CALL XTBLU(X1,5.,60,9,QS,QS1)                                      11851E10
      CALL XTBLU(X2,5.,60,9,QS,QS2)                                      11851E11
      Z1=(QS1+GS)/Y1+Y3-X1
      Z2=(QS2+GS)/Y1+Y3-X2
      IF(Z2) 1,1,2                                                       11851E14
    2 X1=X2
      GO TO 3
    1 Z2=ABSF(Z2)                                                        11851E15
      DBS=X1+0.5*Z1/Z2/(1.+Z1/Z2)                                        11851E16
      CALL XTBLU(DBS,5.,60,9,QS,QGS)                                     11851E17
      GO TO 32                                                           11851
   31 DBS=(1400.+GS+Y2)/(Y1+14.)                                         11851
      QGS=-14.*(DBS-100.)                                                11851
   32 CONTINUE                                                           11851
      CALL TBLU(TW,KWS,XWS,TWS)                                          11851E18
      CALL DBWBDP(DB,WB,DP,WV)                                           11851E19
      QGL=400.-QGS                                                       11851E20
      ZF=ZLEWS*UO/0.243
      WA=((QGL+GL)/CO3+ZF*TWS+CO2*ZFM*WV)/(CO2*ZFM+ZF)
      IF(WCC) 19,20,20
   20 PRINT 10,WA
   19 CONTINUE
      IF(WA-TWS)  101,101,102
  101 IF(WA-WCD) 103,103,102
  103 WA=WV+(QGL+GL)/(CO2*ZFM*CO3)
  102 CALL  DBWWBH(DBS,WA,WBS,H)
      IF(WCC) 21,22,22
   22 PRINT 11,WBS
   21 CONTINUE
      CALL DBWBDP(DBS,WBS,DPS,WA)                                        11851E24
      IF(WCC)  23,24,24
      PRINT 14,DPS
      PRINT 10,WA
   23 CONTINUE
      IF(WCC)  25,16,16
   16 PRINT 4,DBS
```

```
      PRINT 5,QGS
      PRINT 6,TWS
      PRINT 7, DP
      PRINT 8,WV
      PRINT 9,QGL
      PRINT 10,WA
      PRINT 11,WBS
      PRINT 14,DPS
   25 CONTINUE
      CALL EFT1(DBS,WBS,ETS1)
      IF(WCC)  15,17,17
   17 PRINT  12,ETS1
   15 RETURN
      END
```

```
      FOR
      SUBROUTINE  AIRCOI(GA,RW,SP,CF,GW,DBS,WBS,TWI,QAS,QAL,NROW)
C     GA=AIR FLOW  THROUGH COIL ,CFM
C     GW=COOLANT FLOW (LBS/HR,*(SPECIFIC HEAT) ,BTU/HR/DEG=500*GPM FOR H20
C     RW=COIL THERMAL RESISTANCE EXCLUDING AIR FILM RESISTANCE
C     SP=COIL AIR SIDE HEAT TRANSFER  SURFACE PER ROW
C     CF=COIL CONTACT FACTOR PER ROW
C     NROW= COIL ROWS
C     DBS,WBS,=COIL INLET AIR DRY-AND WET-BULB TEMPERATURES
C     TWI   =COIL  COOLANT ENTERING TEMPERATURE
C     QAS =COIL  SENSIBLE  CAPACITY
C     QAL =COIL  LATENT    CAPACITY
      DIMENSION  XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),T(20),W(20
     1),TW(20),TAL(2),TWG(2),FGS(2)
      COMMON  XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS
      T(1)=DBS
      CALL DBWBDP(DBS,WBS,DPS,WX)
      W(1)=WX
      TWG(1)=DBS-1.
      TWG(2)=TWG(1)-1.
      A=SP/(RW*GA*CF*4.5)
    7 DO   100    K=1,2
      TW(1)=TWG(K)
      DO     99     I=1,NROW
      X=T(I)
      Y=W(I)
      Z=TW(I)
      CALL SURFT(A,X,Y,Z,TSX,WSX)
      T(I+1)=T(I)-(T(I)-TSX)*CF
      Z=WSX-W(I)
      IF(Z) 1,2,2
    1 W(I+1)=W(I)-(W(I)-WSX)*CF
      GO TO 3
    2 W(I+1)=W(I)
    3 TW(I+1)=TW(I)-          (SP/(GW*RW))*(TSX-TW(I))
   99 CONTINUE
      NZ=NROW+1
      FGS(K)=TW(NZ)-TWI
  100 TAL(K)=T(NZ)
      TEST=FGS(1)*FGS(2)
      IF(TEST) 4,5,6
    6 TWG(1)=TWG(2)
      TWG(2)=TWG(2)-1.
      GO TO 7
    5 TWL=TWG(1)
      TL=TAL(2)
      GO TO 98
    4 C=ABSF(FGS(1)/FGS(2))
      TWL=(TWG(1)+TWG(2)*C)/(1.+C)
      TL=(TAL(1)+TAL(2))/2.
   98 QAS=1.08*GA*(DBS-TL)
      QAL=GW*(TWL-TWI)-QAS
      RETURN
      END
```

```
      [illegible]
      SUBROUTINE   SURFT(A,TA,WA,TW,TS,WS)
C      SOLVE FOR  TS  FROM 0.243*(TA-TS)+1060.*(WA-WS)=A*(TS-TW)
      DIMENSION  XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),Y(2),F(2)
      COMMON   XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS
      Y(1)=TA
      Y(2)=TA-1.
    5 DO   1   I=1,2
      P1=PV(Y(I),29.92)
      W=0.622*P1/(29.92-P1)
    1 F(I)=A*(Y(I)-TW)-0.243*(TA-Y(I))+1060.*(WA-W)
      TEST=F(1)*F(2)
      IF(TEST) 2,3,4
    4 Y(1)=Y(2)
      Y(2)=Y(2)-1.
      GO TO  5
    3 TS=Y(2)
      GO TO  10
    2 C=ABSF(F(1)/F(2))
      TS=(Y(1)+Y(2)*C)/(1.+C)
   10 P1=PV(TS,29.92)
      WS=0.622*P1/(29.92-P1)
      RETURN
      END
```

```
FUNCTION  FN(X1,X2,Y1,Y2,Z1,Z2,Z3)
P1= X1*Y1/Z1 +X2*Y2/Z2  + Z3
P2= X1/Z1 + X2/Z2
FN=P1/P2
RETURN
END
```

```
      EFFECTIVE TEMPERATURE CALCULATION
      SUBROUTINE  EFT1(DB,WB,EFX)
      DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150),
      EDB(100),EWB(100),ET(50,50)
      COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS,EDB,EWB,ET,KET,NET
      IF(DB-WB)  1,1,2
    1 EFX=DB
      GO TO 15
    2 IF(DB-EDB(29)) 3,4,4                                          11851 44
    3 EFX=0.
      GO TO 15
    4 IF(WB-EWB(30)) 3,5,5
    5 IF(DB-EDB(1))  6,6,7
    7 EFX =100.
      GO TO 15
    6 IX=0
      DO 8   I=1,29                                                 11851 45
      IF(DB-EDB(I))  9       ,10,10
   10 X1=EDB(I)
      X2=EDB(I-1)
      GO TO 11
    9 IX=IX+1
    8 CONTINUE
   11 JY=0
      DO 12 J=1,30
      IF(WB-EWB(J)) 13,14,14
   14 Y1=EWB(J)
      Y2=EWB(J-1)
      GO TO 16
   13 JY=JY+1
   12 CONTINUE
   16 Z11=ET(IX+1,JY+1)
      Z12=ET(IX,JY+1)
      Z22=ET(IX,JY)
      Z21=ET(IX+1,JY)
      IF(Z11*Z12*Z22*Z21) 3,3,17
   17 Z2=Z22+(DB-X2)*(Z21-Z22)/(X1-X2)
      Z1=Z12+(DB-X2)*(Z11-Z12)/(X1-X2)
      EFX =Z2+(WB-Y2)*(Z1-Z2)/(Y1-Y2)
   15 RETURN
      END
```

```
ENTHALPY  CALCULATION  BY   DB AND  WB
 SUBROUTINE  DBWBH(DB,WB,H)
 DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150)
 COMMON  XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS
 CALL  TBLU (WB,KWS,XWS,WS)
 CALL  TBLU (WB,KHW,XHW,HW)
 CALL  TBLU (DB,KWS,XWS,WSS)
 CALL  TBLU (DB,KHA,XHA,HA)
 CALL  TBLU (WB,KHS,XHS,HS)
 CALL  TBLU (DB,KHS,XHS,HSS)
 HAS=HSS-HA
 X=(HS-HW*WS)*HAS-HA*HW*WSS
 Y=HAS-HW*WSS
 H=X/Y
 RETURN
 END
```

```
RELATIVE  HUMIDITY CALCULATION  BY DB AND WB                                 11851811
  SUBROUTINE DBWBRH(DB,WB,PB,RH)                                             11851812
  DIMENSION XWS(150),XHA(150), XHS(150),XHW(150),XFS(150)
  COMMON  XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS                            11851814
  CALL DBWBDP(DB,WB,DP,W)
  CALL  TBLU(DB,KWS,XWS,WS)                                                  11851817
  ZM=W/WS                                                                    11851818
  DBB=DB/10.
  CALL TBLU(DBB,KFS,XFS,FS)
  Z=PV(DB,PB)/PB                                                             11851820
  RH=100.*ZM/(1.-(1.-ZM)*FS*Z)                                               11851821
  RETURN                                                                     11851822
  END
```

```
 WET BULB  CALCULATION   BY  DB AND  W                              11851F02
  SUBROUTINE  DBHWBH(DB,W,WB,H)
  DIMENSION XWS(150),XHA(150),XHS(150),XHW(150),XFS(150)
  COMMON  XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS                   11851F05
  CALL    TBLU(DB,KHA,XHA,HA)                                       11851F06
  CALL    TBLU(DB,KHS,XHS,HS)                                       11851F07
  CALL TBLU(DB,KWS,XWS,WS)
  IF(W-WS) 4,5,5
5 WB=DB
  H=HS
  GO TO 6
4 H=HA+W*(HS-HA)/WS
  X1=DB                                                             11851F10
3 X2=X1-0.5                                                         11851F11
  CALL    TBLU(X1,KHS,XHS,HS1)                                      11851F12
  CALL    TBLU(X2,KHS,XHS,HS2)                                      11851F13
  CALL    TBLU(X1,KWS,XWS,WS1)                                      11851F14
  CALL    TBLU(X2,KWS,XWS,WS2)                                      11851F15
  CALL    TBLU(X1,KHW,XHW,HW1)                                      11851F16
  CALL    TBLU(X2,KHW,XHW,HW2)                                      11851F17
  Z1=HS1-HW1*(WS1-W)                                                11851F18
  Z2=HS2-HW2*(WS2-W)                                                11851F19
  IF(Z2-H) 1,1,2
2 X1=X1-0.5                                                         11851F21
  GO TO 3                                                           11851F22
1 WB=X2+0.5*(H-Z2)/(Z1-Z2)
6 RETURN
  END
```

```
VAPOR PRESSURE CALCULATION
 FUNCTION    PV(X,PB)
 T=X+459.688
 TS=671.688
 TM1=-(7.90298)*(TS/T-1.)
 TM2=(5.02808)*(LOG10F(TS/T))
 TM3=-(1.3816/(10.**(7.)))*((10.**(11.344*(1.-T/TS)))-1.)
 TM4=(8.1328/1000.)*(10.**(-3.49149*(TS/T-1.))-1.)
 ANS1=TM1+TM2+TM3+TM4
 ANS2=10.**(ANS1)
 PV=PB*ANS2
 RETURN
 END
```

```
DEW-POINT CALCULATICN BY DB AND WB
  SUBROUTINE  DBWBDP(DB,WB,DP,W)
  DIMENSICN  XWS(150),XHA(150),XHS(150),XHW(150),XFS(150)
  COMMON XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS
  IF(DB-WB) 1,1,2
1 DP=DB
  CALL TBLU(DB,KWS,XWS,W)
  GO TO  100
2 CALL  TBLU(DB,KHA,XHA,HA)

3 IS FULL.  GIVE ME ANCTHER A3 AND START.
 PERMAMENT TAPE REDUNDANCY WAS DETECTED WHILE READING THE RECORD THAT PRODUCED

  CALL  TBLU(DB,KHS,XHS,HS)
  CALL  TBLU(DB,KWS,XWS,WS)
  CALL  TBLU(WB,KHS,XHS,HSWB)
  CALL  TBLU(WB,XHW,XHW,HW)
  CALL  TBLU(WB,KWS,XWS,WSWB)
  W=WS*(HSWB-HA-HW*WSWB)/(HS-HA-HW*WS)
  Y1=WB
5 Y2=Y1-0.5
  CALL TBLU(Y1,KWS,XWS,Z1)
  CALL TBLU(Y2,KWS,XWS,Z2)
  IF(Z2-W)3,3,4
4 Y1=Y1-0.5
  GO  TO 5
3 DP=Y2+0.5*(W-Z2)/(Z1-Z2)
100 RETURN
  END
```

```
WET  BULB  CALCULATION  BY  DB AND DP                                  1185180
  SUBROUTINE  DBDPWB(DB,DP,WB,W)                                       1185180
  DIMENSICN XWS(150),XHA(150), XHS(150),XHW(150),XFS(150)
  COMMON  XWS,XHA,XHS,XHW,XFS,KWS,KHA,KFS,KHW,KHS                      1185180
  CALL TBLU(DP,KWS,XWS,W)                                              1185180
  CALL DBWWBH(DB,W,WB,H)
  RETURN                                                               1185180
  END
```

```
LINIER   INTERPOLATION                                    11851H0
 SUBROUTINE     TBLU(X,KX,V,Y)                            11851H0
 DIMENSICN V(150)
 J=XINTF(X)                                               11851H0
 L=J-KX+2                                                 11851H0
 LL=J-KX+1                                                11851H0
 VU=V(L)                                                  11851H0
 VL=V(LL)                                                 11851H0
 Y=(VU-VL)*(X-INTF(X))+VL                                 11851H1
 RETURN                                                   11851H1
 END
```

```
      SUBROUTINE    XTBLU(X,DX,KX,LX,V,Y)
      DIMENSION  V(50)                                          11851C0
      J=XINTF(X)
      M=KX+XINTF(DX)*(LX-1)                                     11851C0
      IF(J-KX) 1,2,2                                            11851C0
    1 Y=V(1)
      GO TO 10                                                  11851C0
    2 IF(J-M ) 3,4,4                                            11851C0
    4 Y=V(LX)                                                   11851C0
      GO TO 10                                                  11851C1
    3 DO 6 I=1,LX                                               11851C1
      Z=I                                                       11851C1
      P=KX                                                      11851C1
      Q=P+Z*DX                                                  11851C1
      IF(X-Q) 5,5,6                                             11851C1
    5 Q1=V(I+1)                                                 11851C1
      Q2=V(I)                                                   11851C1
      Y=Q1-(Q1-Q2)*(Q-X)/DX                                     11851C1
      GO TO 10                                                  11851C1
    6 CONTINUE
   10 RETURN                                                    11851C2
      END                                                       11851C2
```

Sample Input and Output Data on M-4 Program

UNDERGROUND FALLOUT SHELTER DATA

INITIAL EARTH TEMPERATURES

TG(1)	TG(2)	TG(3)	TG(4)	TG(5)	TG(6)
70.5	72.0	72.0	72.0	73.0	
70.0	72.0	72.0	72.0	72.0	
69.0	71.0	71.0	71.0	72.0	
67.0	70.0	70.0	70.0	71.0	
67.0	70.0	70.0	70.0	71.0	
67.0	70.0	70.0	70.0	70.0	
67.0	70.0	70.0	70.0	69.0	
67.0	69.0	69.0	69.0	68.0	
67.0	68.0	68.0	68.0	67.0	
67.0	67.0	67.0	67.0	67.0	

INITIAL CONCRETE WALL TEMPERATURE

TC(1)	TC(2)	TC(3)	TC(4)	TC(5)	TC(6)
73.0	73.0	73.0	73.0	73.0	73.0
73.0	73.0	73.0	73.0	73.0	73.0
73.0	73.0	73.0	73.0	73.0	73.0
73.0	73.0	73.0	73.0	73.0	73.0
73.0	73.0	73.0	73.0	73.0	73.0

TIME VARIABLES

DB(N)	TV(N)	CPV(N)	QSUN(N)
70.0	76.0	57.2	
72.0	72.0	47.9	
74.0	74.0	61.9	
75.0	66.0	48.6	
77.0	68.0	55.C	
77.0	66.0	48.6	
76.0	64.0	48.2	
76.0	63.0	47.C	
75.0	62.0	43.5	
75.0	81.0	68.2	
75.0	91.0	71.8	
75.0	92.0	71.4	
77.0	93.0	71.C	
78.0	92.0	68.2	
79.0	88.0	69.9	
80.0	85.0	71.1	
80.0	81.0	71.3	
80.0	79.0	69.1	
80.0	77.0	68.4	
80.0	76.0	71.8	
80.0	79.0	7C.6	
81.0	84.0	73.C	
81.0	87.0	71.9	
80.0	90.0	72.2	
82.0	92.0	71.4	
82.0	92.0	73.C	
83.0	88.0	73.0	
83.0	84.0	71.6	
83.0	82.0	72.3	
83.0	80.0	7C.2	
83.0	79.0	69.1	
82.0	78.0	69.5	
82.0	80.0	7C.2	
82.0	86.0	69.2	
82.0	91.0	71.8	
82.0	92.0	71.4	
83.0	92.0	69.8	
83.0	92.0	71.4	
84.0	88.0	71.4	
84.0	83.0	70.4	
84.0	81.0	69.8	
84.0	79.0	69.1	
84.0	80.0	71.7	
84.0	79.0	7C.6	
84.0	81.0	71.3	
83.0	86.0	72.2	
83.0	90.0	7C.6	
83.0	92.0	69.8	
84.0	92.0	71.4	
84.0	92.0	71.4	
85.0	88.0	71.4	
85.0	83.0	7C.4	
85.0	80.0	70.2	
85.0	80.0	7C.2	
84.0	79.0	72.1	
84.0	79.0	72.1	
84.0	79.0	72.1	

83.0	87.0	71.9
83.0	90.0	72.2
83.0	92.0	69.8
84.0	92.0	71.4
84.0	92.0	71.4
85.0	88.0	73.0
85.0	83.0	72.0
85.0	82.0	70.8
85.0	80.0	70.2
85.0	79.0	70.6
85.0	79.0	70.6
85.0	80.0	73.1
85.0	86.0	72.2
84.0	89.0	72.6
84.0	92.0	71.4
85.0	93.0	71.0
85.0	91.0	70.2
85.0	87.0	70.3
85.0	83.0	70.4
85.0	81.0	69.8
85.0	80.0	70.2
85.0	79.0	70.6
85.0	78.0	71.0
85.0	80.0	71.7
84.0	85.0	72.6
84.0	89.0	72.6
83.0	91.0	71.8
84.0	93.0	71.0
83.0	92.0	71.4
85.0	88.0	71.4
86.0	83.0	70.4
86.0	81.0	71.3
86.0	79.0	70.6
85.0	79.0	70.6
85.0	79.0	70.6
85.0	80.0	71.7
85.0	82.0	73.8
85.0	90.0	72.2
85.0	92.0	71.4
85.0	92.0	71.4
85.0	91.0	71.8
85.0	87.0	70.3
85.0	83.0	72.0
85.0	80.0	71.7
85.0	79.0	72.1
85.0	78.0	71.0
85.0	77.0	71.4
84.0	79.0	72.1
84.0	85.0	72.6
84.0	89.0	72.6
83.0	91.0	73.4
84.0	92.0	71.4
85.0	91.0	71.8
85.0	88.0	69.9
86.0	83.0	72.0
85.0	80.0	71.7
85.0	79.0	70.6
85.0	78.0	71.0
85.0	78.0	71.0
84.0	79.0	73.5

84.0	85.0	72.6
84.0	89.0	72.6
84.0	92.0	73.0
84.0	92.0	71.4
85.0	92.0	73.0
85.0	88.0	73.0
85.0	84.0	70.0
85.0	81.0	71.3
85.0	80.0	70.2
85.0	78.0	71.0
84.0	78.0	71.0
85.0	80.0	71.7
84.0	85.0	72.6
84.0	90.0	72.2
84.0	92.0	71.4
84.0	92.0	71.4
85.0	91.0	71.8
85.0	88.0	69.9
86.0	83.0	72.0
86.0	81.0	71.3
85.0	79.0	70.6
86.0	79.0	70.6
85.0	78.0	71.0
85.0	79.0	72.1
86.0	85.0	72.6
85.0	89.0	72.6
85.0	90.0	72.2
85.0	92.0	73.0
86.0	91.0	71.8
86.0	88.0	69.9
86.0	84.0	70.0
86.0	81.0	71.3
86.0	78.0	71.0
86.0	78.0	72.5
86.0	78.0	71.0
85.0	80.0	71.7
85.0	85.0	72.6
85.0	88.0	73.0
84.0	92.0	71.4
85.0	93.0	72.6
85.0	92.0	71.4
86.0	88.0	69.9
86.0	84.0	71.6
86.0	81.0	71.3
86.0	79.0	69.1
86.0	79.0	72.1
85.0	79.0	72.1
85.0	80.0	71.7
85.0	85.0	71.1
85.0	90.0	72.2
85.0	92.0	71.4
85.0	92.0	71.4
86.0	92.0	71.4
86.0	89.0	71.0
86.0	83.0	72.0
86.0	80.0	71.7
86.0	78.0	71.0
86.0	78.0	71.0
86.0	77.0	71.4
85.0	80.0	73.1

85.0	86.0	72.2
85.0	90.0	72.2
85.0	92.0	71.4
86.0	93.0	71.0
86.0	93.0	72.6
86.0	88.0	71.4
85.0	84.0	71.6
85.0	81.0	71.3
84.0	79.0	70.6
84.0	79.0	69.1
84.0	79.0	70.6
83.0	80.0	71.7
83.0	85.0	71.1
82.0	90.0	70.6
83.0	92.0	71.4
83.0	92.0	71.4
83.0	91.0	71.8
83.0	88.0	71.4
83.0	83.0	72.0
83.0	81.0	71.3
83.0	80.0	71.7
83.0	79.0	70.6
83.0	79.0	72.1
83.0	81.0	72.7
82.0	86.0	72.2
82.0	90.0	72.2

PHYSICAL DATA USED FOR COMPUTATION

S(K)	D(K)	ZL(K)	CK(K)	CG(K)	AC(K)	AG(K)	H(K)	HD(K)
705.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.0000	4.1000
705.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.0000	4.1000
705.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.0000	4.1000
705.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.0000	4.1000
5520.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	0.5000	2.0000
5520.0000	0.8320	9.0000	1.1000	0.7500	0.0360	0.0170	1.5000	6.2000

EG(1)	EG(2)	EG(3)	EG(4)	EG(5)	
0.034	0.034	0.034	0.034	0.034	

EC(1)	EC(2)	EC(3)	EC(4)	EC(5)	EC(6)
0.166	0.166	0.166	0.166	0.461	0.461

TIME	QVS	QVL	QGS	QGL	QWST	QWLT	TWCT	QAS	QAL
2.	0.	0.	106991.	109009.	87773.	15897.	15.	19190.	90163.

CALCULATED SHELTER CONDITION

DBS	DPS	WBS	RHS	ET	TS
82.19	76.22	77.75	82.23	79.74	75.67

EXPOSURES		1	2	3	4	5	6
QWS(M)		4678.7	4678.7	4678.7	4678.7	20201.7	48856.5
QWL(M)		1369.1	1369.1	1369.1	1369.1	10420.3	0.
TWC(M)		1.3	1.3	1.3	1.3	9.8	0.
FLX(M)		8.6	8.6	8.6	8.6	5.5	8.9
TS(M)		75.7	75.7	75.7	75.7	75.0	76.4
CONC.TEMP.	2	74.4	74.4	74.4	74.4	74.4	75.5
CONC.TEMP.	3	73.7	73.7	73.7	73.7	73.9	74.6
CONC.TEMP.	4	73.3	73.3	73.3	73.3	73.5	73.8
CONC.TEMP.	5	72.9	73.1	73.1	73.1	73.3	73.8
EARTH TEMP	1	72.9	73.1	73.1	73.1	73.3	
EARTH TEMP	2	70.1	72.0	72.0	72.0	72.0	
EARTH TEMP	3	69.0	71.0	71.0	71.0	72.0	
EARTH TEMP	4	67.1	70.0	70.0	70.0	71.0	
EARTH TEMP	5	67.0	70.0	70.0	70.0	71.0	
EARTH TEMP	6	67.0	70.0	70.0	70.0	70.0	
EARTH TEMP	7	67.0	70.0	70.0	70.0	69.0	
EARTH TEMP	8	67.0	69.0	69.0	69.0	68.0	
EARTH TEMP	9	67.0	68.0	68.0	68.0	67.0	
EARTH TEMP	0	67.0	67.0	67.0	67.0	67.0	

DBV	DPV	WBV	CFM
76.00	57.23	64.00	0.

TIME	QVS	QVL	QGS	QGL	QWST	QWLT	TWCT	QAS	QAL
24.	-124051.	-370636.	123227.	92773.	41649.	0.	0.	207623.	463408.

CALCULATED SHELTER CONDITION

DBS	DPS	WBS	RHS	ET	TS
79.09	51.23	62.08	37.87	71.83	75.58

EXPOSURES		1	2	3	4	5	6
QWS(M)		2763.7	2473.7	2473.7	2473.7	12093.4	19370.5
QWL(M)		0.	0.	0.	0.	0.	0.
TWC(M)		0.	0.	0.	0.	0.	0.
FLX(M)		3.9	3.5	3.5	3.5	2.2	3.5
TS(M)		75.2	75.6	75.6	75.6	74.7	76.8
CONC.TEMP.	2	74.5	75.0	75.0	75.0	74.5	76.4
CONC.TEMP.	3	73.9	74.5	74.5	74.5	74.2	76.0
CONC.TEMP.	4	73.4	74.1	74.1	74.1	74.0	75.7
CONC.TEMP.	5	73.1	73.9	73.9	73.9	73.9	75.7
EARTH TEMP	1	73.1	73.9	73.9	73.9	73.9	
EARTH TEMP	2	70.6	72.3	72.3	72.3	72.5	
EARTH TEMP	3	68.9	71.1	71.1	71.1	71.9	
EARTH TEMP	4	67.6	70.3	70.3	70.3	71.2	
EARTH TEMP	5	67.1	70.1	70.1	70.1	70.8	
EARTH TEMP	6	67.0	70.0	70.0	70.0	70.0	
EARTH TEMP	7	67.0	69.7	69.7	69.7	69.0	
EARTH TEMP	8	67.0	68.9	68.9	68.9	68.0	
EARTH TEMP	9	67.0	68.0	68.0	68.0	67.3	
EARTH TEMP	0	67.0	67.0	67.0	67.0	67.0	

DBV	WBV	CFM
92.00	77.00	9040.00

TIME	QVS	QVL	QCS	QGL	QWST	QWLT	TWCT	QAS	QAL
48.	-90920.	-373940.	119939.	96061.	28741.	0.	0.	191115.	476000.

CALCULATED SHELTER CONDITION

DBS	DPS	WBS	RHS	ET	TS
79.77	52.00	62.67	38.10	72.41	76.90

EXPOSURES		1	2	3	4	5	6
QWS(M)		2386.5	2034.8	2034.8	2034.8	11491.4	8759.1
QWL(M)		0.	0.	0.	0.	0.	0.
TWC(M)		0.	0.	0.	0.	0.	0.
FLX(M)		3.4	2.9	2.9	2.9	2.1	1.6
TS(M)		76.4	76.9	76.9	76.9	75.6	78.7
CONC.TEMP.	2	75.8	76.4	76.4	76.4	75.4	78.5
CONC.TEMP.	3	75.2	75.9	75.9	75.9	75.1	78.4
CONC.TEMP.	4	74.7	75.4	75.4	75.4	74.9	78.2
CONC.TEMP.	5	74.2	75.1	75.1	75.1	74.8	78.2
EARTH TEMP	1	74.2	75.1	75.1	75.1	74.8	
EARTH TEMP	2	71.1	72.7	72.7	72.7	72.9	
EARTH TEMP	3	69.2	71.3	71.3	71.3	71.9	
EARTH TEMP	4	67.9	70.5	70.5	70.5	71.3	
EARTH TEMP	5	67.3	70.1	70.1	70.1	70.7	
EARTH TEMP	6	67.1	69.9	69.9	69.9	69.9	
EARTH TEMP	7	67.0	69.5	69.5	69.5	69.0	
EARTH TEMP	8	67.0	68.9	68.9	68.9	68.1	
EARTH TEMP	9	67.0	68.0	68.0	68.0	67.4	
EARTH TEMP	0	67.0	67.0	67.0	67.0	67.0	

DBV	DPV	WBV	CFM
90.00	72.21	77.00	9040.00

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13. ABSTRACT

Digital computer programs for the calculation of underground shelter heat transfer are described with respect to their mathematical models, assumption, limitations, parameters, input data and computational techniques. The report also presents comparisons between the calculated shelter thermal environments with the observed for seven different prototype shelters.

It has been found that the simple one-dimensional heat conduction model can accurately simulate the thermal environment in large shelters, although complex three dimensional heat conduction models may be needed for a small and shallow underground conduction.

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'UNCLASSIFIED'

NATIONAL BUREAU OF STANDARDS Dec 1966

140 pages OCD-OS-62-44 1211A

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